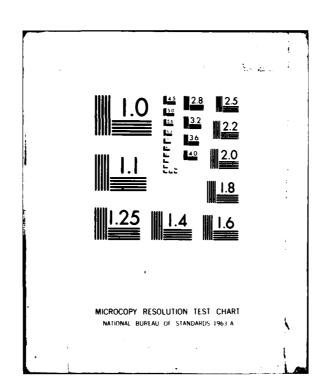
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Side Lobe Cancellation		
The objective of this program was to develop a systematic method of generating adaptive weights through the application of the Batch Covariance Relatation (BCR) algorithm and assess the performance of such weights in and adaptive sidelobe canceller system.		

The following items were developed: (a) A mathematical model representing an adaptive radar antenna operating in a wideband noise jamming (over)

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SECURITY CLASSIFICATION OF THIS PAGE(When Date Entered) environment. The model was formulated as an equivalent baseband transfer function. (b) A complete description of the weight computation procedure for jammer nulling based on the BCR algorithm, including several examples which illustrate its superior numerical characteristics compared to certain other algorithms. (c) A library of modular FORTRAN IV computer programs which implement multiple interference sources, the adaptive radar antenna model, and the BCR algorithm. These were used to extensively evaluate the capability of BCR processing in realistic jammaing scenarios.

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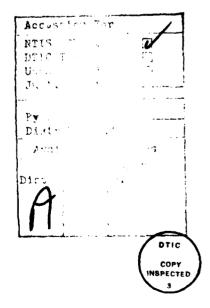
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The authors are indebted to a number of secretaries, S. M. McGovern, C. L. Karseboom, E. A. Shick, K. L. Herslow, and M. J. Morton, who helped with the typing of the manuscript. Our deep appreciation goes to Mrs. Karseboom and Mrs. Herslow whose dedication to perfection in organizing and typing the bulk of the material resulted in the presentable style of the final report.

Finally, on behalf of Motorola, the authors wish to extend their appreciation to Russell Brown and Vincent Vanicola of RADC/OCTS who supported this work and displayed an active interest throughout the duration of the program.



BCR ADAPTIVE PROCESSING

- AN OVERVIEW -

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PREFACE

The work carried out by the Advanced Technology and Systems Analysis Section of the Radar Systems Office at Motorola's Government Electronics Division under contract to RADC/OCTS is presented in a total of six separate technical memoranda written at various stages of the effort.

Although to a large extent these memoranda are self-sufficient, the interested reader may be advised to go through Project Memorandum 8512-06, an overview of the whole effort, before proceeding with the remaining in numerical sequence. As such, if presented in a single volume, the memoranda will be arranged as listed below:

- I. BCR Adaptive Processing An Overview -Project Memorandum 8512-06 March 31, 1981
- II. Definition of Mathematical Model Project Memorandum 8512-01 March 29, 1980
- III. Signal Generation Program
 Project Memorandum 8512-02
 July 20, 1980
- IV. Batch Adaptive Processing and the BCR Process Project Memorandum 8512-03 December 15, 1980
- V. Computer Simulation of BCR Adaptive Process Project Memorandum 8512-04 March 15, 1981
- VI. BCR Adaptive Processing Implementation and Its Performance Evaluation Via Computer Emulation Project Memorandum 8512-05
 March 26, 1981

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3.2	Approach
3.3	Accomplishments
4.0	RECOMMENDATIONS

1.0 INTRODUCTION

In the midst of a strong interference environment, radar and communications equipment could degrade in performance to the point where their intended operation may be rendered practically ineffective. To insure operational survival, future systems must incorporate appropriate interference suppression measures. Adaptive array processing provides a means for suppressing directionally distinct interferences by creating nulls in these directions through a weight adjustment of at least as many antenna elements of a receiving antenna array.

Although cost-effective analog implementation of gradient-type control have been realized, the attention has turned increasingly towards more sophisticated techniques capable of more rapid convergence rates. The increased sophistication of such techniques dictates the need for processing flexibility which may be met most easily by a digital mechanization.

The effort conducted addresses the essential aspects of Batch Covariance Relaxation (BCR) adaptive processing applied to a digital adaptive array processing. In contrast to dynamic algorithms, a batch approach, such as BCR, circumvents the effects of signal dynamics on nulling performance by operating on a single signal batch at one time, thereby diminishing the requirement for fast-convergence.

BCR adaptive processing constitutes an architecturally more efficient alternative to Sample Matrix Inversion. Based on the conjugate gradients algorithm, BCR solves a linear system of equations by means of a finite-step relaxation procedure without the requirement that the inverse of the matrix involved exist. More importantly, its iterative nature lends itself to an architecturally efficient implementation which is particularly suitable to large-scale applications.

The main purpose of the present memorandum is to provide a brief overview of the work accomplished under RADC Contract F30602-80-C-0031. Presented first is a statement of the problem which provided the vehicle for investigating the performance of BCR adaptive processing. Following this, the specific objective, approach and accomplishments are reviewed with reference to the five project memoranda generated at various stages of the effort. Finally, recommendations are given for related future work.

2.0 STATEMENT OF THE PROBLEM

The problem chosen to evaluate BCR adaptive processing relates to the adaptive weight adjustment of a sidelobe nulling subsystem. More specifically, this subsystem involves a main Taylor-weighted large aperture antenna array of 255 omnidirectional elements. Its field pattern is shown in Figure 2-1. In order to suppress undesired sidelobe interference,

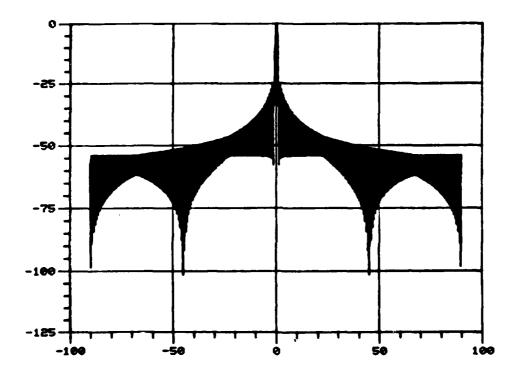


Figure 2-1. Field Pattern of Main Antenna Array

it is assumed that the main antenna may be combined with a number of weight-adjustable omnidirectional auxiliaries located sparsely over the available aperture. It is the purpose of the BCR processor to derive the auxiliary weights adaptively.

The essence of the BCR processor may be described briefly, as follows. Let

 ${s_0(m)}_{m=1}^{M}$ = M-sample main complex baseband scalar signal batch

 $\{\underline{s}(m)\}_{m=1}^{M}$ = M-sample auxiliary complex baseband N-vector signal batch

Then, letting \underline{w} represent the complex weight N-vector applied over the N auxiliaries, the combined complex scalar signal batch is given by

$$\{s_{c}(m)\}_{m=1}^{M} = \{\underline{s}^{T}(m)\underline{w} + s_{o}(m)\}_{m=1}^{M}$$
 (2-1)

If the signals involved constitute primarily undesired interference, then an appropriate criterion for the underlying adaptive array process is the minimization of the combined power in a given batch with respect to the weight vector w. In view of (2-1), the combined power is defined by

$$P_{C}(\underline{w}) = \sum_{m=1}^{M} |s_{C}(m)|^{2}$$
 (2-2)

clearly, a quadratic function of w. Geometrically, $P_c(w)$ represents a hyperparaboloid in (2N+1)-space having a unique minimum value for at least one value of w. We seek a weight-vector w that minimizes $P_c(w)$. The desire colution satisfies the necessary condition that the complex gradient of $P_c(w)$ with respect to w be zero; that is, a value of w which minimizes $P_c(w)$ satisfies

$$\nabla_{\mathbf{W}} \mathbf{P}_{\mathbf{C}}(\underline{\mathbf{W}}) = \underline{\mathbf{0}} \tag{2-3}$$

With (2-1) and (2-2) at hand, it may be shown that condition (2-3) leads to the complex linear system

$$Cw + b = 0 (2-4)$$

where C is the NxN complex Hermitian covariance matrix of the auxiliary signal vector $\underline{\mathbf{s}}$ computed over a given batch; i.e.,

$$C = \sum_{m=1}^{K} \underline{s}^*(m)\underline{s}^{T}(m)$$
 (2-5)

and \underline{b} is the complex cross-correlation N-vector over the same batch, given by

$$\underline{\mathbf{b}} = \sum_{m=1}^{M} \underline{\mathbf{s}}^*(m) \mathbf{s}_0(m) \tag{2-6}$$

Hence, the adaptive array process has been reduced to solving (2-4) for \underline{w} . Formally, the solution is given by

$$w^0 = -C^{-1}b$$
 (2-7)

often referred to as the Sample Matrix Inversion (SMI) solution. Of course, in using (2-7), the inverse, C^{-1} , is assumed to exist. In contrast, the CG algorithm employed in the BCR approach is a numerically robust iterative procedure which begins with an initial estimate \underline{w}^0 and produces the desired solution to (2-4) in a finite number of steps which does not exceed the rank of the matrix C. At each step, the current estimate, \underline{w}^K , is updated to an improved estimate, $\underline{w}^{k+1} = \underline{w}^k - \alpha_k \underline{p}^k$, by optimally relaxing $P_C(\underline{w})$ along the search vector \underline{p}^k . The process terminates when the gradient, $\underline{r}^{K+1} = C\underline{w}^{k+1} + \underline{b}$, is sufficiently small in length with respect to the forcing vector \underline{b} . When the initial estimate \underline{w}^0 is taken to be 0, the final weight estimate is the so-called minimum-norm solution, the solution \underline{w} closest to the origin.

As the weight-vector solution is derived for each batch of signals, it is applied to the same batch and thus forms the corresponding combined signal batch. Since signals are practically frozen within the batch and essentially isolated from neighboring batches, signal dynamics present no particular difficulty to a BCR processor. As such, the convergence-rate requirements of dynamic algorithms is not strictly applicable in batch processing.

3.0 OVERVIEW OF INVESTIGATION

The BCR Adaptive Processing study conducted over the previous several months has been documented in great detail in five separate technical memoranda written in the course of the investigation. Reviewed below is the overall objective, general approach and accomplishments of the effort.

3.1 Objective

The essential objective of the study was to introduce the concept of BCR adaptive processing not only in a mathematically appealing but also in a tangible and practical way. As such, the BCR process was to be formulated in the context of the specific adaptive nulling subsystem discussed in the previous section.

3.2 Approach

A multistaged approach was adopted for accomplishing the stated objective. The important elements constituting the basic approach are as follows:

- Definition of a physically-credible <u>mathematical model</u> of the scenario and system description.
- 2. Preparation of a modular signal generation computer simulation program incorporating the mathematical model. Main and auxiliary signals could thus be generated for a variety of scenario and system parameter specifications.
- 3. <u>Mathematical background</u> and formulation of the BCR adaptive process. Pertinent supporting mathematical theory of the CG algorithm and its possible variations could thus be understood from first principles.
- 4. Preparation of modular BCR simulation program to use signal generation data and provide a detailed numerical summary of the BCR process including nulling performance.
- 5. Preparation of modular BCR performance and plotting program to afford the user the visualization of certain performance observables.
- 6. Discussion of a BCR processor implementation and its performance evaluation via precise computer emulation, an exact model of the hardware mechanization.

3.3 Accomplishments

Following the approach outlined above, the investigation resulted in a number of important accomplishments, such as the following:

- 1. A mathematical model describing the important physical aspects of the scenario and pertinent parameters of the adaptive array system was defined. The detailed mathematical development was reported in Project Memorandum 8512-01. One of the most important contributions of this particular work was the derivation of the equivalent baseband transfer function of the antenna system which describes the transformation of the complex envelope of a given source from incidence on the array, through the receiver and all the way down to baseband. As such, each incident source is viewed as passing through a distinct channel determined by its angle of arrival and the receiver's final IF filter. The received baseband signal at a given port is simply a linear superposition of individual source envelope signals transmitted through their associated equivalent baseband channels.
- 2. The scenario and system description defined in PM 8512-01 was incorporated into a disc file in the form of a clearly descriptive menu from which the user may specify pertinent parameters. Included among these parameters are choices of percent IF and RF bandwidths, specification of IF filter in terms of its low-pass prototype pole locations, the number of incident sources, their associated amplitudes and angles of arrival, specification of main antenna array, locations of auxiliary antenna elements, etc. This input data file has been referred to as SIGGEN:D.

Project Memorandum 8512-02 introduces a "library-based" modular signal generation program, SIGGEN, which uses the system description specified via SIGGEN:D to produce sampled main and auxiliary baseband port signals in a separate output file, SIGGEN:O.

- 3. A complete mathematical development of the BCR process was reported in Project Memorandum 8512-03. Included there is the batch processing concept, the detailed derivation of the CG algorithm and several numerical examples illustrating its numerical characteristics. Presented also is a new constrained formulation of the CG algorithm which may be applicable not only to fully adaptive array systems but also to partially adaptive ones.
- 4. Project Memorandum 8512-04 was devoted to the evaluation of the BCR process via computer simulation. It includes a detailed description of a refined version of the signal generation program, SIGGEN, a BCR simulation program, BCRS, and a BCR performance evaluation and plotting program, BCRP. All three of these program are modular in construction and share modules from a common libarary, RADAR:LIB.

An extensive explanation as to how to use these programs is given. It is shown how the output of each is used as part of the input for the next program. As such, SIGGEN:0 is used to construct BCRS:D, the input data file to BCRS. In turn, its output file, BCRS:0, is used to construct BCRP:D, the input data file to BCRP.

As mentioned before, SIGGEN:O includes sampled main and auxiliary complex baseband signals. Output file BCRS:O includes the convergence or relaxation characteristics in terms of gradient metric and combined

power reduction at each iteration, as well as the associated evolution of adaptive weight iterates. Also computed is the combined-port signal along with the achieved nulling performance.

Although an output file BCRP:0 is created, it is most interesting in graphical form. The TEKTRONIX graphical output provided by BCRP includes a graph of main and combined signal amplitudes, source-related channel amplitude responses before and after adaptation, field-patterns at the vicinity of source-angles of arrival before and after adaptation and, finally, mainbeam pattern before and after adaptation.

Results from a large number of <u>examples</u> are presented graphically. Included among these examples are cases involving scenarios with continuous, blinking, wideband, multiplath equal and unequal power sources. System configurations with <u>singly</u> or <u>multiply-tapped</u> ports are also considered.

5. A practical <u>TTL implementation</u> of a BCR processor has been included in Project Memorandum 8512-05. Although the design given applies specifically to a 4-port system, the general approach applies to other dimensionalities.

A modular computer emulation program, BCRM, incorporating the exact hardware design is also included. Using an input data file, BCRM:D, which includes SIGGEN:O, BCRM carries out the detailed adaptive fixed-point arithmetic employed by the hardware implementation. The entire arithmetic activity of the BCR processor is written into an output file BCRM:O. Three examples demonstrate the effectiveness of the implementation.

6. Probably, the most important accomplishment of the BCR adaptive processing study is the library of software modules and the four major programs made of these library modules. With these at hand, the user may examine the performance of the BCR processor for any number of examples other than the ones presented. Following the convention of the library approach, the user may add to the sophistication of the software already developed.

For purposes of easy reference, the next few pages contain a complete catalog of the modular library, RADAR:LIB. Listed there are source module names and special JCL programs indicating authors, date of origin and revision.

Table 3-1. Modular Program Library, RADAR:LIB

1.000 2.000	RADAR PROGRAM LIBRARY CATALOG	PARY CATALOG	
6.000 6.000 6.000	REVISION 1 APRIL	2, 1981	
	AUTHOR(S)	URIGINATED	REVISED
10.000			
11.000 12.000 ADOT8:S	S. M. DANIEL	9/12/79	3/19/81
14.000 15.000 AGC:S	S. M. DANIEL I. KERTESZ	1/15/81	2/02/81
17.000 18.000 ALLPLOT:S 19.000	S. M. DANIEL I. KERTESZ	A/23/80	2/03/81
20.000 21.000 AMPH:S 22.000	S. M. DANIEL I. KFRTESZ	4/19/80	7/01/80
23.000 24.000 ANTWT:S 25.000	S. M. DANIEL I. KERTESZ	4/19/80	9/01/80
2K.000 27.000 RCREML:S 28.000	S. M. DANTEL I. KERTESZ	4/15/79	3/25/81
29.000 31.000 31.000	S. M. DANIEL I. KERTES7	8/10/80	1/06/81
33,000 BCKMAIN:S	S. M. DANIEL I. KERTESZ	7/23/80	8/12/80
35.000 BCRMMAINIS 37.000 BCRMMAINIS	S. M. DANIEL I. KERTESZ	8/ /79	3/11/81
39.000 ACMEXECIS 40.000 ACMEXECIS 41.000	S. M. DANJEL I. KERTESZ	1/15/81	3/19/81

42.000	BCKMSET:S	S. M. DANIEL I. KERTESZ	7/23/80	3/25/81
4.000 4.000 6.000 6.000	BCRSET:S	S. M. DANIFL I. KERTESZ	7/23/80	1/54/81
4 4 4 4 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6	BCRSIM:S	S. M. DANIEL I. KERTESZ	4/15/78	9/17/80
51.000	ACHPMAIN:S	S. M. DANIEL I. KEHTESZ	7/23/80	2/ 3/81
54.000 54.000 65.000	BCRPSET:S	S. M. DANJEL I. KERTESZ	7/23/80	2/13/81
57.000 57.000 58.000	816SGN:S	S. M. DANIEL I. KERTESZ	1/27/91	3/11/81
600 600 600 600 600 600 600 600 600	BLINKS	I. KERTESZ S. m. Daniel	6/12/80	6/16/80
63.000 64.000	CAND8:S	S. M. DANIEL I. KERTESZ	9/23/80	1/06/81
64.000 64.000 64.000	CREML 15	S. M. DANJEL I. KERTESZ	8/15/79	3/25/81
40.000 40.000	CHANNEL:S	S. M. DANIEL I. KERIESZ	5/04/80	1/52/81
72.000 73.000	CMBSGNL:S	S. M. DANIEL I. KERTESZ	08/90/6	9/13/80
75.000	CMPCHNL:S	S. M. DANIEL I. KERTESZ	A/04/80	1/30/81
78.000	CSEMLIS	S. M. DANIEL I. KERTESZ	8/15/79	3/25/81
81.000	FFT2:S	PROF. P. RANSOM S. M. DANTFL	4/15/69	9/01/80
94.000	FIELDIS	S. M. DANIEL	8/04/80	1/31/81

85.000		I. KERTESZ		
0000	FILTERIS	S. M. DANIEL I. KERTESZ	4/19/80	6/23/80
0000	FORMIS	S. M. DANIEL I. KERTESZ	4/15/78	9/13/80
0000 0000 0000 0000	FORMATIS	S. M. DANTEL I. KERTFSZ	4/15/78	3/17/81
94.000	IMPULS:S	S. M. DANIEL I. KERTESZ	5/11/80	6/07/80
	9: 700	S. M. DANIEL G. C. WANG	6/20/80	7/01/80
00000	אני חסר	S. M. DANIEL G. C. WANG	6/22/80	6/23/80
000.000	JCLBCRP: AL	S. M. DANIEL	1/06/81	2/26/81
000	JCLBCRS: AL	S. M. DANIEL	1/06/81	2/26/81
000000000000000000000000000000000000000	JCLSIGIAL	S. M. DANIEL G. C. WANG	6/21/80	2/26/81
13.000	LIMITIS	S. M. DANIEL I. KERTES?	8/15/79	3/25/81
15.000	PL015:S	S. M. DANIEL I. KERTESZ	08/9/6	2/ 2/81
13.000	PWRSUPIS	S. M. DANIEL I. KERTESZ	9/11/40	9/12/80
21.000 22.000 22.000	RCNORM: S	S. M. DANIEL I. KERTESZ	8/31/78	1/26/81
24.000 25.000	ROUNDC:S	S. M. DANIEL I. KERTESZ	61/ /6	3/11/81
27.000	ROUNDR:S	S. M. DANIEL	61/ /6	3/11/81

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12A.000		I. KERTESZ		
130.000	RVIS	S. M. DANIEL I. KEPTESZ	4/15/78	3/17/81
134.000	RWINGIS	S. M. DANIEL I. KERTESZ	4/19/80	8/13/80
135.000	PRTSGNL:S	S. M. DANIEL I. KERTESZ	6/01/80	1/05/81
139.000	SCALE	S. M. DANIEL I. KERTESZ	8/15/79	3/19/81
142.000	SCATD:S	S. M. DANIEL I. KERTESZ	A/15/79	3/17/81
145.000	STGMAINES	S. M. DANIEL I. KERTESZ	4/19/80	1/02/81
144.000 144.000	SIGNALIS	S. M. DANIEL I. KERTESZ	6/08/80	9/01/80
151.000	\$16 \$£ 115	S. M. DANIEL I. KERIESZ	6/01/80	1/15/81
154.000 154.000 155.000	SKIPR:S	S. M. DANJEL I. KERTESZ	2/23/81	2/23/81
157.000 158.000 159.000	TTEKS:S	S. M. DANIEL I. KERTESZ G. C. WANG	8/01/80	2/23/81
161.000 162.000	UPDATE:S	S. M. DANIEL I. KERTESZ	8/15/79	3/19/81
164.000 165.000 167.000 167.000	WITER:S	WITEH:S S. M. DANIEL 9/13/80 9/13/80 I. KERTESZ	9/13/80	9/13/80

4.0 RECOMMENDATIONS

Based on the results of the present study, there are two possible avenues for future productive work involving BCR adaptive processing. A software effort may be defined to increase the capability of the modular library in order to address adaptive performance in more realistic scenarios and operational system configurations. A companion effort must address increasingly more sophisticated, efficient and flexible architectures of BCR adaptive processors.

The modular library already developed is amenable to a systematic improvement and growth. As such, realistic scenarios involving desired signals, interfering sources and ambient noise may be incorporated via modifications to existing modules or creation of new such modules. The constrained BCR formulation, which may be applicable in certain operational situations, must be accommodated in the existing BCRSIM module. The resulting module may now be applicable to solving both unconstrained and constrained minimum mean square problems which arise in radar signal processing. Besides adaptive nulling, applications such as adaptive clutter cancelling, spectrum estimation and spatial or temporal adaptive filtering come to mind.

Since BCR adaptive processing has a wide applicability, it makes sense to exploit promising architectural options that further take advantage of its underlying algorithmic structure and lead to cost-effective, technically reliable and flexible implementations. For example, a serialized BCR processor design involving a single complex multiplier/adder combination would lend itself to a variable dimensionality application. Implied here, of course, is the need for appropriately flexible timing, control and storage architectures and certainly programmability. Finally, future BCR implementations should tend toward distributed, self-diagnosing and fault-tolerant processing architectures with the aim of enhancing computational capability and operational survivability.

DEFINITION OF MATHEMATICAL MODEL

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1.0 INTRODUCTION

Consider a surveillance radar adaptive array system employing a large-aperture narrow-beam low-sidelobe main linear antenna array in an adjustable weighted combination with a number of omnidirectional auxiliary antenna elements with the aim of suppressing sidelobe interference. A credible evaluation of the dynamic performance of such an adaptive system cannot be conducted unless the analysis employs a sufficiently faithful mathematical model that describes the pertinent physical phenomena involved.

Given an arbitrary signal arriving from a certain azimuth direction, a reliable mathematical model must describe the received form of the signal at each antenna port incorporating the dependence on bandwidth. Beyond this point, the main and auxiliary signals must be down-converted to some convenient intermediate frequency (IF) and band-limited there by appropriate filtering. Expected mismatch and misalignment between the different IF filters must be included in the model, thus reflecting the description of the received signals up to that stage.

In order to analyze the performance of subsequent digital processing, which is usually accomplished at baseband, the mathematical model must describe the signals down to baseband, taking into account any baseband filter mismatch if it is deemed significant. In effect, the signal at each receiver baseband port constitutes the complex envelope of the original signal at the source transmitted through an equivalent "channel" that incorporates the antenna and receiver characteristics already mentioned.

An equivalent channel may be defined for each combination of source and receiver. Clearly, the cancellation performance of a baseband adaptive array process will depend directly on the quality of match between these channels. The discussion that follows develops the mathematical model that describes the general channel and defines the received baseband signal. Specific considerations are given to receiver mismatch, wideband operation, and the multipath phenomenon.

2.0 MATHEMATICAL MODEL

The specific aim in this section is to define the mathematical model that describes the propagation of an arbitrary signal from its source through an arbitrary linear antenna array, through its accompanying receiver down to baseband. To begin with, an appropriate videband signal is first defined. Subsequently, a linear antenna array configuration is defined appropriate for adaptive array processing. Finally, the equivalent baseband channel description is developed in a clear step-by-step process constituting the "transfer function" from the complex envelope of the source signal to the complex envelope that comprises the desired baseband signal. The actual representation of the baseband signal then follows.

2.1 Transmitted Signal

At its source, a given transmitted signal may be defined by the general expression ${}^{\prime}$

$$x(t) = P(t) \cos \left[2\pi f_1 t + \phi_1(t) + \phi_0\right]$$
 (2-1)

where P(t) is a noise-like amplitude-modulation waveform, $\phi_1(t)$ is an arbitrary phase modulation and ϕ_0 is a fixed arbitrary initial phase.

For the purpose of analyzing the performance of an adaptive array system, it is not strictly necessary that x(t) be of the complexity (2-1). It would suffice, for example, to define an appropriate transmitted signal by

$$x(t) = P(t) \cos 2\pi f_1 t$$
 (2-2)

where P(t) is chosen to be a biphase noiselike sequence with a chip-rate high enough to yield a nearly uniform line spectrum over the band of interest about f_1 . It is important to note that intrinsic channel characteristics associated with this band will come into play and imprint their effect upon the ultimate signal at the receiver's baseband. Since phase modulation does not add any further observability of channel characteristics, its use is only academic. Finally, the initial fixed phase ϕ_0 may be taken to be zero without loss of generality, except perhaps in the most degenerate of cases in which received baseband signals might be strictly real or imaginary thus occupying only one of the quadrature channels. It is not expected that this situation will be of concern in 'he sequel.

In view of the above argument and considering the relative simplicity in the subsequent analysis and computer simulation, the transmitted signal will be assumed to be of form (2-2). It should be noted, however, that a phase shift will be induced at the antenna upon reception of (2-2).

2.2 Antenna Configuration

An antenna configuration appropriate for adaptive radar processing is one involving a multielement main linear array in combination with a number of omnidirectional auxiliary elements.

2.2.1 Main Linear Array

More specifically, the main linear array will be assumed to be comprised of at least 250 equally-spaced omnidirectional elements weighted according to a Taylor window and phased broadside. For convenience, the 25 dB Taylor window [1] to be used will be approximated by a simpler expression that defines the ℓ -th weight by

$$a(l) = 1.0 + 0.5 \cos \frac{2\pi(l-(L+1)/2)}{L}$$
 (2-3)

where $\ell \in [1,L]$, L is the total number of elements comprising the linear array.

Although the distance between elements is ususally taken to be equal to the half-wavelength of the center frequency of operation f_0 , it is an easy matter to choose the element separation to be some fraction of $\frac{\lambda_0}{2}$, namely,

$$d = d_0 \frac{\lambda_0}{2} \tag{2-4}$$

where, typically, $d_0 \le 1$. This flexibility is needed in analyzing system performance over a large operating frequency range.

It should also be noted that even though the uniform-spacing assumption may be restrictive from the point of view of analyzing the practical beamforming capability of the linear array, it poses no such restriction in the investigation of its performance in an adaptive array system as envisioned here.

2.2.2 Auxiliary Elements

The weight-adjustable auxiliary antenna elements will be assumed to be omnidirectional, although, in general, they may be chosen to have a more complex field pattern. However, more important than this is the fact that the auxiliary elements need to be randomly emplaced over the entire aperture of the main array if they are to be effective in the adaptive process.



In choosing a particular emplacement of auxiliary elements over the aperture of the main array, two important issues are involved. First, the need for spatial resolution, that is at least equivalent to that of the main array, dictates that the available auxiliaries span the main antenna aperture. Second, in view of the relatively small number of auxiliaries and their consequent large physical separations (>> λ_0) over the main antenna aperture, the emplacement of the auxiliaries must be sufficiently random in order to circumvent undesirable blind regions.

Referring to geometries of poor cancellation, the blind region phenomenon is most pronounced when the auxiliary elements form a uniformly spaced thinned array. Most commonly explained as the grating lobe effect, this undesirable feature is a manifestation of spatial aliasing. A remedy for minimizing spatial aliasing is random spatial sampling, which results in improved performance of the underlying adaptive array process. The validity of random spatial sampling (random emplacement of auxiliary elements) in dealing with the aliasing problem is supported by a considerable amount of investigation in the area of random array theory [2] and, specifically, with the synthesis of directive low-sidelobe random thinned arrays [3], [4].

Recent investigations at Motorola Government Electronics Division have addressed the blind region problem in connection with sidelobe cancelling [5]. A linear dependence hardware test provided direct verification that the blind regions are due to the aliasing structure of the auxiliary subarray. Based on further measurements, it was concluded that it may not be possible to completely eliminate blind regions in adaptive arrays, even with random emplacement of auxiliaries. It may be that the ultimate way around this problem is the use of an excess of degrees of freedom, namely, more auxiliary elements than strictly necessary.

2.3 Equivalent Baseband Channel

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Given a source signal of the form (2-2) incident onto a uniform linear array attached to a given receiver, the resulting baseband signal happens to be the complex envelope output of a properly defined baseband channel whose input, in general, is the complex envelope of the original signal at the source. Of course, in view of (2-2), the input complex envelope is strictly real. Following a discussion of a complex bandpass signal representation, two forms of the so-called equivalent baseband channel are derived, a general form and a simpler alternate one.

An experiment conducted by D. Fraser and S. M. Daniel at Motorola's Government Electronics Division, Scottsdale, Arizona, in 1977 predicted the existence and precise location of blind regions of an adaptive array system by exercising only the auxiliary subarray.

2.3.1 Complex Signal Representation

Before attempting to characterize the equivalent baseband channel, it is necessary to introduce the notion of complex envelope. To begin with, consider the general bandpass signal

$$x(t) = P(t) \cos (2\pi f_1 t + \phi)$$
 (2-5)

where P(t) is a lowpass pseudonoise function whose bandwidth is a sufficiently small fraction of the carrier frequency f_0 , [6] and ϕ is an arbitrary fixed phase induced by a receiving antenna. Since x(t) may be written as

$$x(t) = \frac{P(t)}{2} \left[e^{j(2\pi f_1 t + \phi)} + e^{-j(2\pi f_1 t + \phi)} \right]$$
$$= \frac{e^{j\phi}}{2} P(t) e^{j2\pi f_1 t} + \frac{e^{-j\phi}}{2} P(t) e^{-j2\pi f_1 t}$$
(2-6)

Letting $P(f) = \Im{\{P(t)\}}$, the Fourier Transform of x(t) is given by

$$X(f) = \frac{e^{j\phi}}{2} P(f-f_1) + \frac{e^{-j\phi}}{2} P(f+f_1)$$
 (2-7)

clearly, a conjugate symmetric function about the origin, f=0. Figure 2-1 shows the corresponding amplitude spectrum, |X(f)|, indicating positive and negative-frequency portions by $X^+(f)$ and $X^-(f)$, respectively.

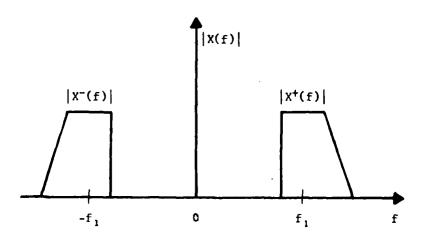


Figure 2-1. Symmetric Amplitude Spectrum of Real Bandpass Signal x(t).

Consider now the downconversion of $\mathbf{x}(t)$ to baseband by mixing it with cos $2\pi f_1 t$ and its quadrature, -sin $2\pi f_1 t$, followed by ideal lowpass filtering to reject the $2f_1$ components. Figure 2-2 depicts this downconversion process applied to $\mathbf{x}(t)$ and resulting to the inphase and quadrature components, I and Q, which comprise the complex baseband signal

$$\zeta(t) = P(t)e^{j\phi} \tag{2-8}$$

In view of (2-7), the Fourier Transform of (2-8)

$$Z(f) = e^{j\phi}P(f)$$
 (2-9)

is, clearly, twice the positive-frequency half of the bandpass complex spectrum of x(t), $X^{\dagger}(f)$, translated toward the origin by a displacement of f_1 . Its amplitude spectrum, |Z(f)|, is shown in Figure 2-3.

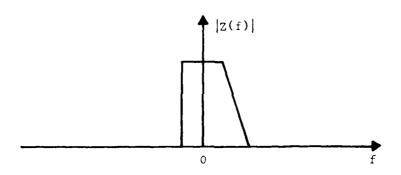


Figure 2-3. Amplitude Spectrum of Complex Baseband Signal ζ(t)

The complex baseband signal, $\zeta(t)$, is also known as the complex envelope of the bandpass signal x(t). Given an arbitrary bandpass signal x(t), its complex envelope may be determined in a way analogous to the above example.

In general, the desired complex envelope is the inverse Fourier transform of twice the positive frequency half of the complex spectrum of x(t), $X^{\dagger}(f)$, translated toward the origin by an amount equal to the oscillator frequency f_{g} , which may not necessarily be equal to f_{1} . As such, in view of (2-6) and (2-7), the determination of the complex envelope is facilitated by dealing directly with the complex representation of x(t); namely,

$$z(t) = P(t)e^{j(2\pi f_1 t + \phi)}$$
 (2-10)

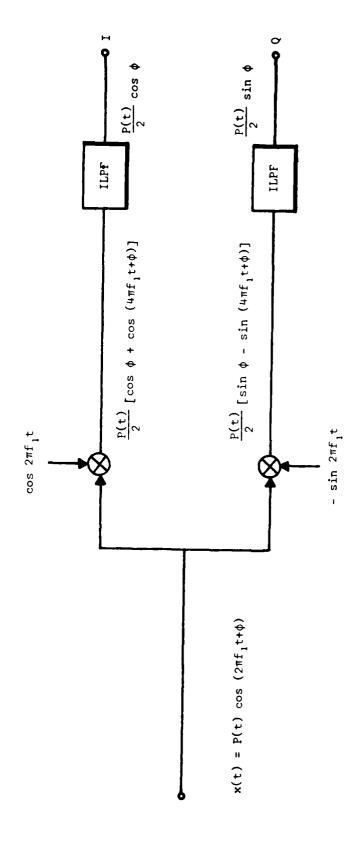


Figure 2-2. A Baseband Downconversion of the Bandpass Signal x(t),

whose Fourier transform is exactly

$$Z(f) = 2X^{\dagger}(f) = e^{j\phi}P(f-f_1)$$
 (2-11)

Then, the spectrum of the complex envelope associated with a downconversion of $\mathbf{f}_{\mathbf{0}}$ is given by

$$Z(f) = 2X^{\dagger}(f+f_0) = e^{\hat{j}\phi}P(f+f_0-f_1)$$
 (2-12)

and the complex envelope by

$$\zeta(t) = P(t)e^{j\phi}e^{j2\pi(f_1-f_0)t}$$
 (2-13)

a simple frequency translation of (2-9), as expected. Figure 2-4 summarizes the relationship between x(t), z(t) and $\zeta(t)$, in terms of their respective amplitude spectra.

It should be noted here that the complex signal, z(t), is sometimes referred to as the complex pre-envelope of x(t). Clearly, x(t) happens to be the real part of z(t); that is,

$$x(t) = Re\{z(t)\}$$
 (2-14)

It is also noteworthy that a phase shift of θ on x(t) may also be written as

$$\tilde{\mathbf{x}}(t) = \operatorname{Re}\left\{e^{j\theta}\mathbf{z}(t)\right\} \tag{2-15}$$

involving the complex multiplication of z(t) by $e^{j\theta}$. Equivalently, by (2-10) and (2-13)

$$x(t) = \operatorname{Re} \left| \zeta(t) e^{j2\pi f_0 t} \right| \tag{2-16}$$

and

$$\tilde{\mathbf{x}}(t) = \operatorname{Re} \left| \zeta(t) e^{j\theta} e^{j2\pi f_0 t} \right|$$
 (2-17)

which implies that the phaseshift θ may be effected at baseband, involving, again, complex multiplication. Obviously, the phaseshifted complex envelope

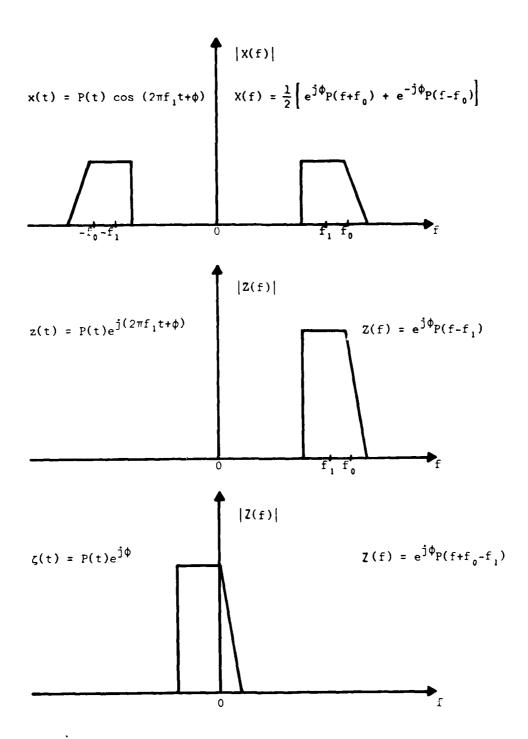


Figure 2-4. Relationships between amplitude spectra of x(t), z(t), and ζ (t), the bandpass signal, the complex pre-envelope and the complex envelope, respectively. Note that the baseband downconversion shift is $f_0 \neq f_1$.

is given by

$$\tilde{\zeta}(t) = e^{j\theta} \zeta(t)$$
 (2-18)

It should be emphasized at this point that although (2-8) seems to be an intuitively appealing and logical expression for the complex envelope of x(t), in general, f_1 is not known or is not even meaningful. Typically, the bandpass character of x(t) is established via appropriate filtering and f_0 is chosen to be somewhere at the center of the band. The important criterion for downconversion is that x(t) be limited within a band that does not exceed $2f_0$, so as to allow for effective filtering out of the $2f_0$ spectrum that is produced in the underlying mixing process. Only then does the notion of complex envelope discussed above make sense.

2.3.2 General Form

Assuming the source signal (2-2), the general form of the equivalent base-band channel is derived in three stages; that is, the part from source through antenna, through the final IF stage, and finally, through to baseband, as suggested in Figure 2-5.

2.3.2.1 Source through Antenna

According to the discussion in Section 2.3, the complex pre-envelope of the source signal (2-2) is given by

$$z(t) = P(t)e^{j2\pi f_1 t}$$
 (2-19)

Given a linear array of uniformly-spaced omnidirectional elements with weighting $\{a_\ell\}_{\ell=1}^L$ and spacing d given by (2-4), let signal (2-19) be incident onto this antenna at an angle θ measured clockwise from broadside. According to the geometry of Figure 2-6, the complex pre-envelope at the antenna terminal is simply

$$z_{A}(t) = \sum_{\ell=1}^{L} a_{\ell} P(t+\tau_{\ell}) e^{j2\pi f_{1}(t+\tau_{\ell})}$$
 (2-20)

where τ_{ℓ} is the time advance in the received signal at the ℓ -th element with respect to reference at the origin of the x-y coordinate system in Figure 2-6.

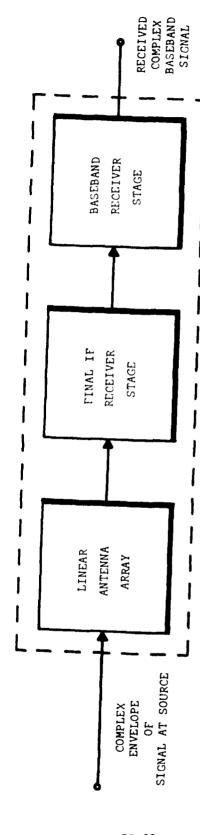


Figure 2-5. Three Stages of the Equivalent Baseband Channel.

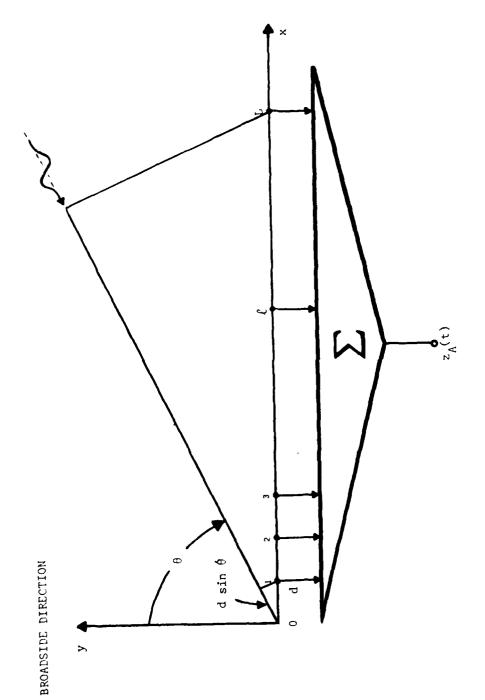


Figure 2-6. Source Signal and Antenna Geometry.

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In view of (2-4), τ_{ℓ} is given by

$$\tau_{\ell} = \frac{\ell d \sin \theta}{c}$$

$$= \ell d_0 \frac{\lambda_0}{2c} \sin \theta$$

$$= \frac{\ell d_0 \sin \theta}{2f_0}$$
(2-21)

where, as mentioned previously, $d_{\mathfrak{p}}$ is a dimensionless quantity less than or equal to unity.

For simplicity, consider the general ℓ -th element of the summation in (2-20); namely,

$$z_{\ell}(t) = a_{\ell}P(t+\tau_{\ell})e^{j2\pi f_{\ell}(t+\tau_{\ell})}$$
 (2-22)

Its Fourier transform is given by

$$Z_{\ell}(f) = a_{\ell} \int_{-\infty}^{\infty} P(t+\tau_{\ell}) e^{j2\pi f_{1}(t+\tau_{\ell})} e^{-j2\pi f t} dt$$

$$= a_{\ell} e^{j2\pi f \tau_{\ell}} \int_{-\infty}^{\infty} P(t+\tau_{\ell}) e^{-j2\pi (f-f_{1})(t+\tau_{\ell})} d(t+\tau_{\ell})$$

$$= a_{\ell} P(f-f_{1}) e^{j2\pi f \tau_{\ell}} \qquad (2-23)$$

which, in view of the previous discussion, is a positive-sided transform. The corresponding transform of the complex envelope of (2-22) is simply the translation of (2-23) by the baseband local oscillator frequency f_0 ; that is,

$$Z_0(f) = a_0 e^{j2\pi(f_0+f)\tau \ell} P(f+f_0-f_1)$$
 (2-24)

whence, the complex envelope is

$$\zeta_{\chi}(t) = a_{\chi} \mathfrak{F}^{-1} \{ Z_{\ell}(f) \}$$

$$= a_{\ell} \mathfrak{F}^{-1} \{ F(f + f_{0} - f_{1}) \} * \mathfrak{F}^{-1} \{ e^{j2\pi (f_{0} + f)\tau} \ell \}$$

$$= a_{\ell} P(t) e^{j2\pi (f_{0} - f_{1})t} * e^{j2\pi f_{0}\tau} \ell \delta(t + \tau_{\ell})$$
(2-25)

which, by the sifting property of the δ -function, reduces to

$$\zeta_{\ell}(t) = a_{\ell} e^{j2\pi f_0 \tau} \ell P(t+\tau_{\ell}) e^{j2\pi (f_1 - f_0)(t+\tau_{\ell})}$$
 (2-26)

a simple f_0 translation of (2-22), as it should be. The significance of (2-25), however, is that it characterizes the transfer function from the signal source to the ℓ -th antenna element of the array in Figure 2-6. Of course, the transfer function up to the antenna terminal consists of a summation of such terms over all the antenna elements. As such,

$$\zeta_{A}(t) = P(t)e^{j2\pi(f_{1}-f_{0})t} \cdot \sum_{\ell=1}^{L} a_{\ell}e^{j2\pi f_{0}\tau_{\ell}} \delta(t+\tau_{\ell})$$
 (2-27)

which suggests the structure of the channel from signal source to antenna terminal, as shown in Figure 2-7. Indicated there is the augmented transmitted envelope.

$$\zeta(t) = P(t)e^{j2\pi(f_1-f_0)t}$$
 (2-28)

presented at the input of the antenna array transfer function

$$A(f) = \sum_{\ell=1}^{L} a_{\ell} e^{j2\pi(f_0 + f)\tau_{\ell}}$$
 (2-29)

and resulting in the desired received complex envelope (2-27).

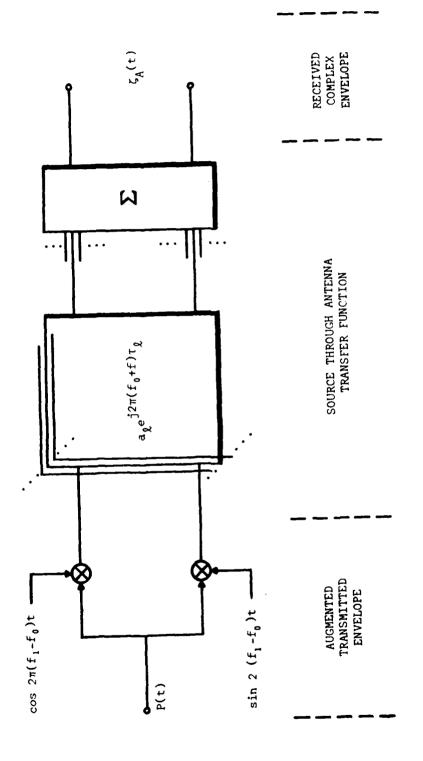


Figure 2-7. Mathematical Model of Equivalent Baseband Channel from Signal Source to Antenna Array Terminal.

2.3.2.2 Source through Final IF

Assume that the processing bandwidth of the receiver connected to the antenna terminal is essentially established by the final IF filter whose transfer function is given by H(f). Then, the Fourier transform of the complex pre-envelope for the l-th element may be written as

$$Z_{\ell}(f) = a_{\ell}P(f+f_{0}-f_{I}-f_{1})e^{j2\pi(f+f_{0}-f_{I})\tau_{\ell}}H^{+}(f)$$
 (2-30)

whence, the Fourier transform of the envelope becomes

$$Z_{\ell}(f) = a_{\ell}P(f+f_{0}-f_{1})e^{j2\pi(f+f_{0})\tau_{\ell}}H^{+}(f+f_{1})$$
 (2-31)

and the actual complex envelope is found, as before, to be

$$\zeta_{\ell}(t) = a_{\ell}P(t)e^{j2\pi(f_1-f_0)t} * \mathfrak{F}^{-1}\left[e^{j2\pi(f_0+f)\tau_{\ell}} H^{+}(f+f_1)\right]$$
 (2-32)

Figure 2-8 suggests the derivation of the received envelope of the ℓ -th element carried to the output of a final IF filter, showing amplitude spectrum of the pre-envelope, |Z(f)|, the positive-frequency IF-filter amplitude response, $|H^{\dagger}(f)|$, and, finally, the spectrum magnitude of the received baseband complex envelope, |Z(f)|.

The received envelope by the entire antenna array at the final IF filter output is given by summation of (2-32) over the elements of the array; namely,

$$\zeta_{IF}(t) = P(t)e^{j2\pi(f_1-f_0)t} * \mathfrak{F}^{-1} \left\{ \sum_{\ell=1}^{L} a_{\ell} e^{j2\pi(f_0+f)\tau} \ell H^{+}(f+f_I) \right\}$$
 (2-33)

The equivalent baseband channel from signal source through the antenna array and the final IF filter is shown in Figure 2-9.

2.3.2.3 Source through Baseband

At the last downconversion stage from final IF to baseband, individual I and Q filters must be used to reject the 2f spectrum that results from the

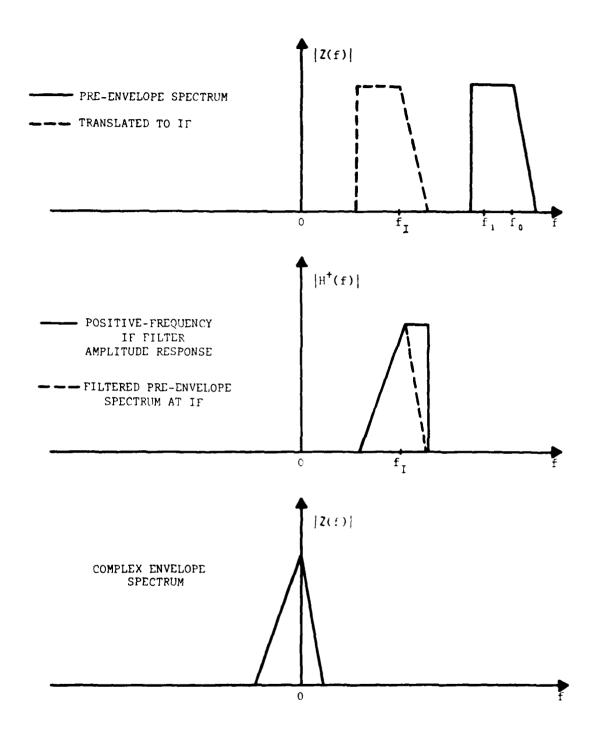


Figure 2-8. Evolution of Complex Envelope Amplitude Spectrum from Original Source Signal Pre-Envelope and Final IF Filter Response.

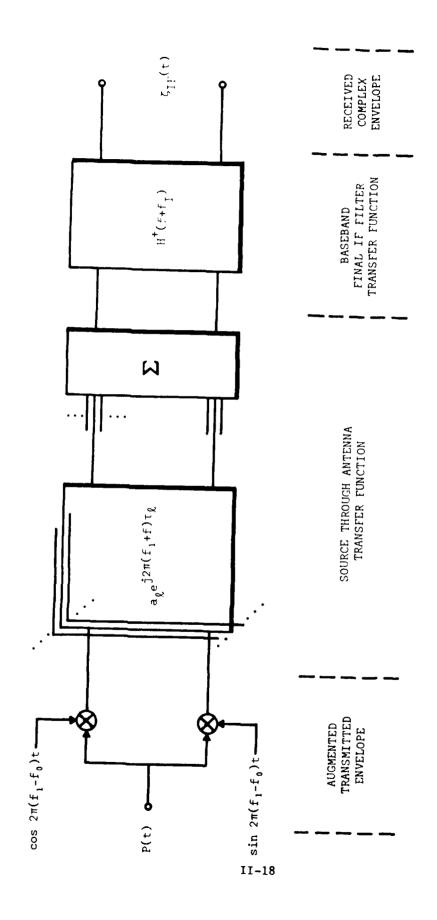


Figure 2-9. Mathematical Model of Equivalent Baseband Channel from Signal Source through Antenna Array, to Final IF Filter Output.

underlying mixing process. Because of limited physical tolerances these two filters may not, in general, be assumed identical and thus should be distinguished by transfer functions $H_{\rm I}(f)$ and $H_{\rm Q}(f)$, respectively. Figure 2-10 gives the mathematical model of the general form of the equivalent baseband channel from signal source to baseband. The received envelope in this case may be specified by defining the real and imaginary parts separately; that is,

$$\text{Re } \zeta_{B}(t) = P(t)e^{j2\pi(f_{1}-f_{0})t} * \mathfrak{F}^{-1} \left\{ \sum_{\ell=1}^{L} a_{\ell}e^{j2\pi(f_{0}+f)\tau_{\ell}} H^{+}(f+f_{1})H_{1}(f) \right\}$$

$$\text{Im } \zeta_{B}(t) = P(t)e^{j2\pi(f_{1}-f_{0})t} * \mathfrak{F}^{-1} \left\{ \sum_{\ell=1}^{L} a_{\ell}e^{j2\pi(f_{0}+f)\tau_{\ell}} H^{+}(f+f_{1})H_{Q}(f) \right\}$$

$$\text{(2-34.2)}$$

It should be mentioned that although (2-34) characterizes the desired baseband channel quite generally, it remains possible to further simplify the expressions by invoking certain reasonable assumptions. The resulting alternate characterization, although simpler, succeeds in embodying the essential features of the system that account for the substantial source of relative distortion between channels.

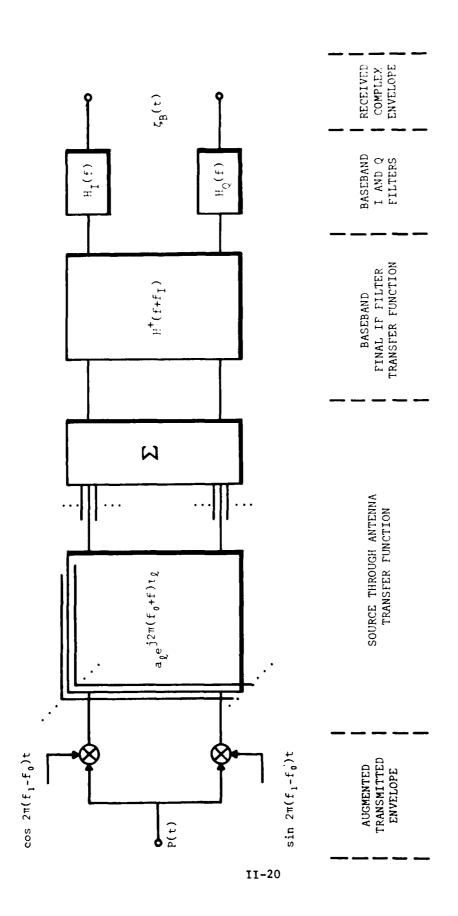
2.3.3 Alternate Form

It is common practice in receiver design that the final IF filter establish the operating bandwidth. In downconverting to baseband, the nearly identical baseband filter transfer functions, $H_{\rm I}(f)$ and $H_{\rm Q}(f)$, need not be as selective as the IF transfer function, H(f). The function of baseband filtering is to reject the 2f spectrum resulting from the final stage of mixing in the downconversion process. In view of this fact, the equivalent baseband channel as characterized by (2-34) reduces to the simpler form of (2-33).

Another observation to be made at this stage is that from the point of view of assessing the performance of adaptive processing, it is not essential that the spectrum of P(t) be centered about a carrier frequency f_1 different from f_0 . Choosing $f_1 = f_0$, reduces (2-33) to the simpler received envelope expression

$$\zeta_{B}(t) = P(t) * \mathfrak{F}^{-1} \left\{ \sum_{\ell=1}^{L} a_{\ell} e^{j2\pi(f_{0}+f)\tau} \ell H^{+\prime} f_{I} \right\}$$
(2-35)

The associated equivalent baseband channel is considerably simpler, as shown in Figure 2-11.



Mathematical Model of Equivalent Baseband Channel from Signal Source through Antenna Array, through Final IF Filter, down to Baseband. Figure 2-10.

Jana AMEN

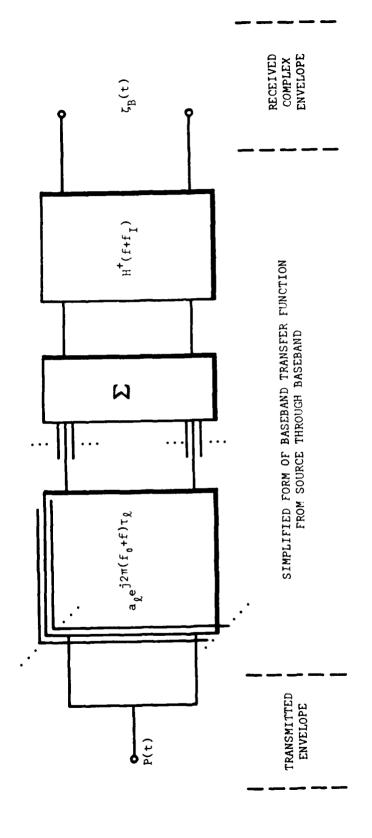


Figure 2-11. Mathematical Model of Alternate Form of Equivalent Baseband Channel from Source through Baseband.

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2.4 Received Baseband Signal

The form of the baseband signal to be adapted for subsequent analysis will be (2-35), the simplest expression for the received complex envelope at baseband. Letting the equivalent baseband channel transfer function be given by

$$C(f) = \sum_{\ell=1}^{L} a_{\ell} e^{j2\pi(f_0+f)\tau_{\ell}} H^+(f+f_I)$$
 (2-36)

associated with a complex impulse response c(t), the received complex envelope at baseband (2-35) may be rewritten, more explicitly, as

$$\zeta_{R}(t) = P(t) * c(t)$$

$$= \int_{-\infty}^{\infty} P(\tau)c(t-\tau)d\tau$$
 (2-37)

This last expression suggests the practical means for computing a sequence of sampled values of the complex envelope (2-37), namely, a discrete convolution of sampled values of P(t) and a finite M-sample impuse response approximating c(t); that is,

$$\zeta_{B}(n) = \sum_{m=1}^{\min(n,M)} P(n+1-m)c(m)$$
 (2-38)

Of course, it is understood that these samples must occur at the Nyquist rate, or, more precisely, at twice the cutoff frequency of the equivalent baseband channel.

3.0 SYSTEM CONSIDERATIONS

The operational effectiveness of an adaptive array system depends directly on a number of physical factors which will tend to establish bounds on its ultimate nulling performance. Whereas a dynamic signal environment will bring about a performance degradation that can vary considerably according to algorithm, other pertinent physical factors such as receiver mismatch, operational bandwidth, and multipath effects account for performance limits independent of algorithm.

3.1 Signal Dynamics

Continuous noise interferring sources do not present any particular difficulty to the nulling performance of even the simplest of adaptive algorithms such as the LMS [7], [8]. However, blinking interferences could conceivably degrade the performance of adaptive array systems employing even more sophisticated dynamic algorithms [9].

In the present contract, the study of the Batch Covariance Relaxation (BCR) algorithm [10] is motivated not only by its potentially efficient architectural implementation but just as importantly, by its batch processing operation, which accounts for a certain level of immunity to a dynamic signal environment. This necessary feature of any future adaptive array process will be elaborated further in a future memorandum intended to describe the essential aspects of the BCR process.

3.2 Receiver Mismatch

A very fundamental physical limitation on the performance of an adaptive array system is the relative matching between the main and auxiliary-channel receivers. Mismatch among receivers is due to filter mismatch at a point of highest selectivity in the downconversion chain.

Typically, the receiver operating bandwidth is established at the final IF stage whether or not the process that follows remains at IF or takes place at a subsequent baseband stage. In this situation, the final IF filter mismatch is due to two design inaccuracies; that is, center-frequency alignment and percent-bandwidth deviation. At baseband, the I and Q lowpass filters need only reject the $2f_{\rm I}$ spectrum and hence may be wideband compared to the IF, thereby not adding appreciably to the overall mismatch.

Alternatively, it may make sense to consider establishing the receiver operating bandwidth at baseband by sufficiently narrow separate I and Q lowpass filters whose transfer functions, $H_{\rm I}({\rm f})$ and $H_{\rm O}({\rm f})$, may deviate in percent-bandwidth.

As already discussed, receiver mismatch may be attributed to deviations in both IF and baseband filter characteristics. For the purposes of the present investigation, consideration will be limited to mismatch that is entirely due to final IF filter deviations, consistent with the typical receiver implementation.

3.3 Wideband Operation

In developing the expression for the transfer function of the equivalent baseband channel in Section 2.0, the corresponding linear array transfer function has been shown to be

$$A(f) = \sum_{\ell=1}^{L} a_{\ell} e^{j2\pi(f_0 + f)\tau_{\ell}}$$
 (3-1)

where $\{a_{\ell}\}_{\ell=1}^{L}$ is the antenna weighting sequence and τ_{ℓ} is the negative time delay at the ℓ -th element relative to the origin. For a uniform element spacing, the use of (2-21) simplifies (3-1) to

$$A(f) = \sum_{\ell=1}^{L} a_{\ell} e^{j\ell \pi d_{0} \sin \theta (1 + \frac{f}{f_{0}})}$$
 (3-2)

where θ is the angle of arrival measured from broadside.

For $\theta \approx 0$, A(f) exhibits nearly constant amplitude and linear phase characteristics over a wide variation of f about f_0 . However, with increasing aperture (large L), bandwidth (large f) and θ , A(f) will exhibit an increasing measure of amplitude and phase distortion. This trend is manifested by an increased sensitivity in the sidelobe structure of the radiation pattern. More specifically, at a sufficiently large angle θ , a pattern null at some frequency f will not remain such over the operating bandwidth. As a consequence, the transfer function over the band of interest could exhibit a stopband as indicated in Figure 3-1.

The difficulty of cancelling a single interference arriving at a far sidelobe of the large main array by combining with it a singly-weighted omnidirectional auxiliary is clearly seen. In the latter case, the antenna transfer function will exhibit nearly constant amplitude and linear phase over the bandwidth B. The two transfer functions will simply not match with the single degree of freedom provided by one complex auxiliary weight.

3.3.1 Tapped Delayline Option

Achieving a so-called "wideband null" is synonymous to matching the auxiliary channel to the main one. This may be accomplished by using multiple auxiliary taps in the form of a tapped delayline. The number of taps to be used depends directly on the complexity of the main channel response. On the other hand, the time-spread of the taps need not exceed the maximum time delay expected over the main antenna aperture.

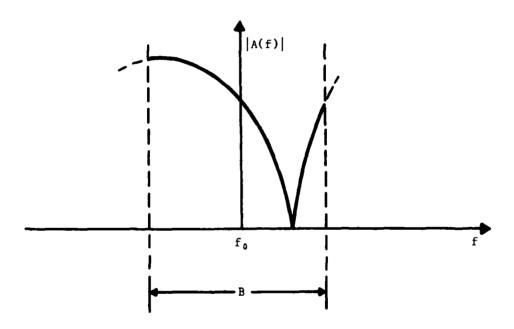


Figure 3-1. Potential Stopband Behavior of Large Antenna Array Transfer Function at a Far Sidelobe With Wide Operational Bandwidth B.

The general problem of matching one channel with another by means of a tapped delayline has been addressed previously in a specific application to equalization [10]. Although the present situation is no different, some care must be exercised that the tap weight adjustment does not deteriorate the quality of the established main beam. Of course, depending on the antenna scheme and adaptive algorithm employed, this concern may or may not be significant. In a fully-adaptive antenna scheme the tap weights must be constrained to maintain a desired beam and low sidelobes while simultaneously suppressing interferences. In a sparsely adaptive antenna arrangement that is being considered presently, the tap weights need to be constrained so as to maintain the integrity of the main beam, something that is most crucial when using a dynamic algorithm and less so when using a batch algorithm.

3.3.2 Single Tap Option

The effect of a delayline tap-weighting may be accomplished equivalently by using a sufficiently large number of singly-tapped auxiliaries. Of course, this approach may be undesirable because of the fact that it would mean a large increase in the number of receivers used. On the other hand, spread randomly over the aperture, the singly-weighted auxiliaries could conceivably act in a more optimal way to simultaneously provide channel matching and interference suppression. Although this alternative may not apply to a space-fed antenna structure, it does apply to a corporate-fed one that is presently being considered.

3.4 Multipath Phenomenon

The mathematical model developed in Section 2.0 is valid when considering an antenna array by itself and ignoring mutual coupling between elements. While it is recognized that interelement coupling will tend to limit the achievement of the desired main array pattern, or hamper adaptive beamforming there is no such concern in the partially adaptive array system considered here.

A phenomenon of much greater concern which could severely limit nulling performance is multipath. In a practical deployment of any antenna system, nearby supporting structures and other scattering bodies within a wide field of view can easily account for alternate paths via which a signal could arrive at the antenna, besides the expected direct path.

3.4.1 Channel Description

The multipath phenomenon may be integrated conveniently in the description of the equivalent baseband channel. Specifically, given the direct and an



alternate path, the resulting compound channel is as shown in Figure 3-2. To be noted, there, are the portions of the primary and alternate paths originating from the common source and terminating at the common input to the baseband IF filter transfer function. The distinction in the two paths is attributed not only to the extra relative delay in the alternate path, but, also to its baseband antenna array transfer function. The latter distinction is based on the fact that the alternate path angle of arrival is necessarily different from that of the primary path. More precisely, the primary and secondary path antenna transfer functions are given, respectively, by

$$A(f) = \sum_{\ell=1}^{L} a_{\ell} e^{j2\pi(f_{0}+f)\tau_{\ell}}$$

$$A'(f) = \sum_{\ell=1}^{L} a_{\ell} e^{j2\pi(f_{0}+f)\tau_{\ell}}$$
(3-3)

where τ_ℓ and τ_ℓ are the distinct negative time delays at the ℓ -th element relative to a convenient origin. These time delays are given by

$$\tau_{\ell} = \frac{\ell d_{0} \sin \theta}{2f_{0}}$$

$$\tau_{\ell} = \frac{\ell d_{0} \sin \theta}{2f_{0}}$$
(3-4)

where θ and θ are the corresponding angles of arrival measured clockwise from broadside. The delay transfer function associated with the alternate path is given by

$$D(f) = c'e^{-j2\pi(f_0+f)\tau'}$$
(3-5)

where c' is generally a complex constant representing amplitude and relative phase of the secondary signal in relation to the primary one, and τ' is the associated relative delay.

The extension of the channel description to any number of alternate paths is obvious from the above. The received complex envelope is computed in a

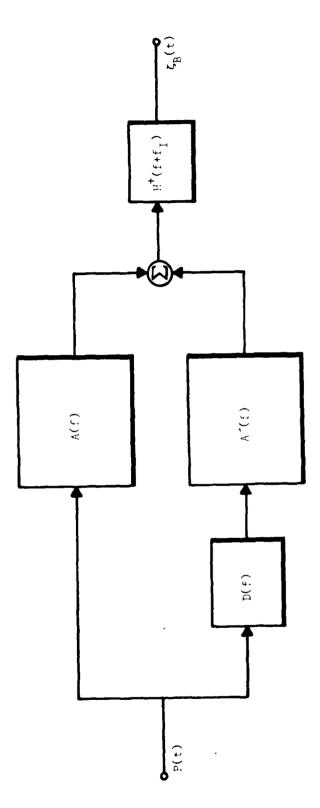


Figure 3-2. Equivalent Baseband Compound Channel Combining the Primary and one Alternate Path from the Source to the Array System.

similar way as already suggested in Section 2.0. That is, with the compound transfer function defined, the desired baseband signal may be expressed as a discrete convolution of the source signal envelope with the channel impulse response according to (2-38).

3.4.2 Effect and Remedies

As shown above, the compound channel transfer function for a two-path situation is of the form

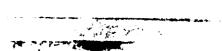
$$C(f) = A(f) + D(f)A'(f)$$
(3-6)

If $A'(f) \approx A(f)$, C(f) will be characterized by a rippled amplitude response, in view of (3-5). The amplitude of the ripple will depend directly on C' and its period on T'. A very similar effect should result in the general case when $A'(f) \neq A(f)$, although the ripple may be somewhat randomized, especially with increased operating bandwidth.

Although rippled amplitude responses will be induced in any antenna transfer function by multipath, it is improbable that the fine structures would match for two different antennas. It is not surprising then that channels corresponding to a multielement main array and a single element auxiliary would differ considerably. As a consequence, it may generally be impossible to provide proper cancellation of a multipath signal incident onto the main array by combining it with a singly-weighted auxiliary. Extra degrees of freedom will be needed to deal with cancellation in a multipath environment, and even more with increasing operating bandwidth.

One possible way to provide effective sidelobe cancellation for a wide operating bandwidth in the presence of multipath is to use a channelized approach. This scheme utilizes a bank of filters to subdivide the operating band and seeks individual adaptive weights for each. Conceivably, if the subdivision is fine enough so that the multipath-induced ripple is not noticeable within an individual filter band, the corresponding single complex weight per filter would suffice. One possible disadvantage in this approach is the potential difficulty in maintaining a certain matching tolerance in the filters comprising the filter bank. More generally, spectral-domain adaptive processing may be used [12].

Two other means for dealing with cancellation in multipath involve the use of tapped delayline auxiliaries or an equivalent multiplicity of singly-weighted auxiliaries, as already mentioned in Section 3.4. The advantage of either of these two approaches over the channelized scheme is that no additional distortion is introduced. Otherwise, the total number of adaptive weights, the degrees of freedom used, are essentially the same in each case.



4.0 REMARKS

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The main objective in the present memorandum has been to develop a mathematical model that would reasonably describe the transformation of a source signal through a linear antenna array down to the baseband of its associated receiver. In accomplishing this, an equivalent baseband channel has been defined in terms of a transfer function that relates the source signal envelope at its input to the received complex envelope at its baseband output. Clearly, then, the received complex envelope may be expressed as a convolution of the input source envelope with the channel impulse response. The channel transfer function has been modeled to take into account spatial dispersion depending on the angle of arrival and antenna configuration, incorporating, as well, the associated receiver characteristics. Doing this is crucial in evaluating the performance of an adaptive array system, since it involves combining the main antenna and its receiver to a number of auxiliaries and their associated receivers, with differing characteristics embodied in the basic mathematical model.

A secondary objective of the present memorandum is to address some system issues that pertain to the general performance characteristics of an adaptive array system. Besides inter-receiver mismatch, some attention is focused onto the intrinsic difficulties that may be encountered in a wideband operation, and appropriate means for circumventing a potentially poor performance. The multipath phenomenon is also examined and possible remedies against its effects on performance are discussed. Multiple degrees of freedom are recommended for effective nulling performance both in the case of wideband operation as well as in a multipath situation. Degrees of freedom may be realized via a multiplicity of singly-weighted randomly emplaced auxiliaries, multiply tapped delayline auxiliaries or through receiver channelization using a filter bank or more generally via spectral weighting.

In defining the mathematical model as described in this memorandum, an attempt has been made to incorporate the most prominent limitations in adaptive array performance within the realm of one possible antenna configuration. Antenna aperture dispersion, receiver mismatch, wideband operation, and multipath effects, however, constitute important limitations to general adaptive array performance. Further limitations such as cable reflections and mixergenerated noise were not incorporated in the model. Their effects have been considered of secondary importance assuming, of course, proper design.

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SIGNAL GENERATION PROGRAM

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1.0 INTRODUCTION

Froject Memorandum 8512-01 has presented a fairly authentic mathematical model which can serve to describe the transmission of a noise signal through a linear antenna array and its associated receiver, all the way down to baseband. It has been shown that the complex baseband signal from a given signal source at some azimuth angle of incidence with respect to the antenna array happens to be the envelope of the source signal transmitted through an equivalent baseband channel which incorporates both receiver and antenna characteristics, including an explicit dependence on the angle of arrival. More specifically, the received complex baseband signal may be derived via a convolution of the source signal envelope with the complex impulse response of the equivalent baseband channel. Assuming linearity, the received baseband signal due to a number of source signals arriving from distinct angular directions is the superposition of their corresponding individual channel transmissions.

The present memorandum describes the development of a structured FORTRAN IV program for the purpose of generating received baseband signals at the multiple ports of an antenna system consisting of a Taylor-weighted large-aperture main linear array and a number of omnidirectional auxiliaries sparsely disposed over the aperture. Taking into account the underlying mathematical model already defined, pertinent system parameters are normalized in order to allow for easy generalization. Overall system and scenario description is provided via a carefully constructed input data file, SIGGENO:D, consisting of an easily readable table of user-selectable system parameter values. The actual signal generation program identified by the acronym SIGGENO is modularized into a number of elementary function-oriented subroutines for the sake of clarity, flexibility and adaptability to future growth.

The collection of the elementary subroutines, the source modules, comprise the signal generation source library. The corresponding set of compiled binary modules comprise the associated binary library. Through an appropriate job control language program, the composite binary module, SIGGENO:B, is synthesized from a selected set of binary modules. An executable load module, SIGGENO:L, is subsequently generated. Given the input data, SIGGENO:D, appropriate execution of SIGGENO:L generates the desired baseband port signals and stores them in an output data file, SIGGENO:O.

The validity of the signal generation program, SIGGENO, is ascertained via a successful demonstration of BCR adaptive processing using a specific set of signal data, SIGGENO:0, and an existing BCR simulation program. Actual simulation results are presented.

Keeping in mind the intent of a large-scale applicability of SIGGENO, it has been optimized for minimum-core usage. An attempt to time-optimize the program by means of partitioning turned out to be rather ineffective. Some recommendations for future program additions and modifications are made.

2.0 PARAMETRIC SYSTEM DESCRIPTION

Consider a multiport antenna system consisting of a Taylor-weighted main linear antenna array in conjunction with a number of omnidirectional auxiliaries, emplaced nonuniformly over the main antenna aperture. Given a number of noise signal sources incident onto the antenna system from distinct azimuth angles, we wish to derive received baseband signals at each of the antenna ports by means of a computer simulation program.

A logical development of a clear, efficient and flexible signal generation program must follow a concise parametric system description of the baseline system. With this information at hand, it will be possible to identify elementary system functions, define their mechanization into dedicated subroutine modules and establish a structured computer simulation program that should enhance system understanding, exhibit a high degree of flexibility and allow for a natural adaptability to efficient future growth.

The objective in the present section is to give a parametric system description of the underlying mathematical model and the normalization of some important parameters that will allow for useful generalization of results.

2.1 Mathematical Model

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Project Memorandum 8512-01 [1] has already provided a mathematical model that describes the baseband reception of a noise signal incident onto a linear antenna array from a given angular direction. In fact, the received complex baseband signal has been shown to be

$$\zeta_{B}(t) = P(t) \div c(t)$$
 (2-1)

where

P(t) = the real-valued zero-mean envelope of the incident noise-source signal.

$$c(t) = \mathfrak{F}^{-1}\{c(f)\}\$$
 (2-2)

= the equivalent baseband channel complexvalued impulse response that characterizes the transmission of the incident noise envelope through the linear array and down to baseband, thus yielding the received baseband signal, $\zeta_B(t)$.

$$C(f) = \sum_{\ell=1}^{L} a_{\ell} e^{j2\pi(f_0 + f)\tau} \ell H^{+}(f + f_{I})$$
 (2-3)

- = the equivalent baseband channel transfer function associated with impulse response c(t).
- $\{a_{1}\}$ $\mathcal{L}_{=1}^{L}$ = the L-element linear antenna array weighting sequence.
 - f = the carrier frequency of the incident
 noise signal, taken also to be the center
 frequency of the system's RF band.

$$\tau_{\ell} = \frac{\ell d_0 \sin \theta}{2f_0} \tag{2-4}$$

- = the negative time-delay at the l-th antenna element with respect to a reference origin
- l = antenna element number
- d₀ = the interelement spacing factor, a
 dimensionless positive constant indicative
 of the amount of half-wavelength spacing
 between the uniformly-spaced antenna array
 elements at the center RF frequency, f₀.
- θ = the azimuth angle of incidence of the noisesource signal, onto the linear antenna array, measured clockwise from its broadside direction
- H[†](f+f_I) = the positive-frequency transfer function of the receiver's final IF filter translated to baseband.
 - $f_{\bar{I}}$ = the center frequency of the receiver's IF band.
 - f = baseband frequency ranging around DC.

It should be clear from (2-1), (2-2) and (2-3) that the equivalent baseband channel transfer function, C(f), relates the input incident noise-source signal envelope, P(t), to the output received complex baseband signal, $\zeta_B(t)$. More precisely, (2-1) expresses $\zeta_B(t)$ as a convolution of P(t) with the equivalent baseband channel impulse response. To be noted here is the explicit dependence of the baseband channel transfer function, C(f), on the angle of arrival, θ . Assuming linearity, this implies that, in the general case involving a multiplicity of directionally-distinct noise-source signals, a received baseband port signal is the superposition of individual contributions from each noise-source signal via its associated distinct baseband channel.

Figure 2-1 shows a single-port linear antenna array system receiving three directionally-distinct signals. According to the mathematical model discussed above, the contribution of each incident signal to the actual received baseband port signal is simply its transmission through its associated baseband channel as indicated in Figure 2-2. Note that although the receiver's IF baseband transfer function is common to all channels, they are distinguished by their distinct baseband antenna transfer functions which will generally vary with angle of arrival. Clearly, in order to accommodate a situation involving $N_{\rm n}$ distinct noise sources and $N_{\rm p}$ antenna ports, it is necessary to specify $N_{\rm n} \times N_{\rm p}$ distinct baseband channels.

2.2 Normalized Model

Although the baseband channel transfer function given in (2-3) could be employed, as is, in a computer simulation program, it would be more desirable to eliminate its dependence on absolute frequency values of f, $f_{\rm I}$ and $f_{\rm 0}$. A normalized model would allow for a more meaningful interpretation and generalization of results. As a consequence, the user need not be concerned with specifying actual frequencies and bandwidths, but could instead deal with normalized baseband frequency, f, and normalized bandwidth at IF and RF.

2.2.1 Normalized Baseband Frequency

The basis for normalizing the mathematical model of the equivalent baseband transfer function, C(f), begins with a logical normalization of the baseband frequency, f. In view of existing convention of defining filters in terms of their lowpass prototypes having a 3-dB cutoff radian frequency of unity, Ω_0 =1, it makes sense to define a normalized baseband frequency, f, accordingly. As a consequence, normalized radian frequency is understood to be defined by

$$\Omega = \frac{\omega}{\omega_c} \tag{2-5}$$

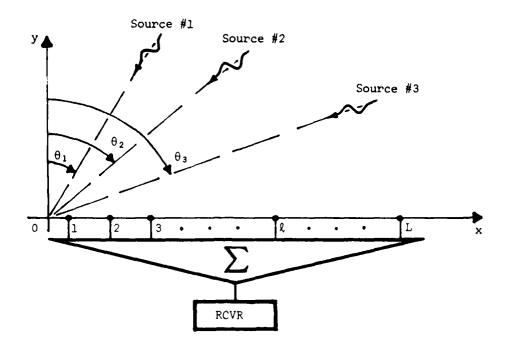


Figure 2-1. Single-Port Linear Antenna Array System with Three Directionally Distinct Incident Sources.

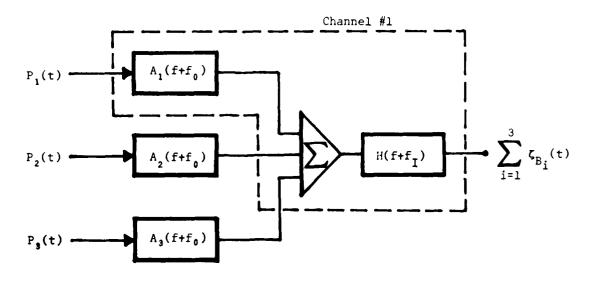


Figure 2-2.

Baseband Port Reception of Multiple
Directionally-Distinct Noise-Source
Signals Via Superposition of Individual
Baseband Channel Receptions

where, $\omega_{\rm C}$ is the actual cutoff radian frequency and ω is the corresponding actual radian frequency. It is then logical to normalize the baseband frequency, f, in accordance to (2-5) in the sense that the final IF positive-frequency transfer function, which shapes the baseband spectrum in a generally asymmetric way about $\omega=0$, is attributable to a lowpass prototype filter.

In practice, the 3-dB cutoff frequency $f_C=\omega_C/2\pi$ is often referred to as the lowpass bandwidth of a lowpass filter. Recognizing that the lowpass filter is symmetric about the origin, we will henceforth refer to its baseband bandwidth of $2f_C=\omega_C/\pi$. Accordingly, its normalized radian bandwidth at baseband is equal to 2. Also, in order to eliminate the burden of π -handling we will systematically convert the expression of C(f) to one involving only Ω . In making this transition, the function symbol will remain the same to preserve association with original notation, even though it is recognized that the transformation $f+\omega/2\pi$ leads to a function distinctly different from C.

2.2.2 Normalized IF Filter

The transfer function for the final IF filter may be derived via a bandpass transformation of a lowpass prototype filter having desired characteristics. More precisely, given a K-pole lowpass prototype filter transfer function

$$H_{LPP}(s) = \prod_{k=1}^{K} \frac{P_k}{(s-P_k)}$$
 (2-6)

the transformation [2]

$$s + \frac{1}{2} \left(s + \frac{\Omega^2 I}{s} \right) \tag{2-7}$$

leads to the equivalent bandpass transfer function

$$H_{BPP}(s) = \prod_{k=1}^{K} \frac{p_k}{\frac{1}{2}(s + \frac{\Omega^2 I}{s}) - p_k}$$
 (2-8)

where $\Omega_{\rm I}$ is the radian IF frequency normalized by $\omega_{\rm C}$. Assuming, tacitly, that the IF bandwidth has not changed appreciably from its value of 2 at

baseband, we may define the system parameter

$$c_1 \equiv \frac{2}{\Omega_I} \tag{2-9}$$

to be the fractional bandwidth at IF. We may now incorporate c_1 in (2-8) and evaluate $H_{\rm BPP}(s)$ on the j Ω -axis. Letting

$$s = j\Omega = j(\Omega_T + \delta\Omega)$$
 (2-10)

it is possible to characterize the behavior of $H_{\rm BPP}(\Omega)$ in the neighborhood of $\Omega_{\rm I}$. Then, using (2-9), it is possible to express HBPP as a function of $\delta\Omega$ which should be recognized as the normalized baseband radian frequency.† To begin with, applying (2-10) into (2-7), we get, in view of (2-9),

$$\frac{1}{2} \left(\mathbf{s} + \frac{\Omega^{2} \mathbf{I}}{\mathbf{s}} \right) = \frac{1}{2} \left[\mathbf{j} \left(\Omega_{\mathbf{I}} + \delta \Omega \right) + \frac{\Omega^{2} \mathbf{I}}{\mathbf{j} \left(\Omega_{\mathbf{I}} + \delta \Omega \right)} \right]$$

$$= \mathbf{j} \frac{\Omega_{\mathbf{I}}}{2} \left[1 + \frac{\delta \Omega}{\Omega_{\mathbf{I}}} - \frac{1}{1 + \frac{\delta \Omega}{\Omega_{\mathbf{I}}}} \right]$$

$$= \mathbf{j} \frac{\delta \Omega}{2} \left[\frac{\delta \Omega}{\Omega_{\mathbf{I}}} + \frac{\delta \Omega / \Omega_{\mathbf{I}}}{1 + \frac{\delta \Omega}{\Omega_{\mathbf{I}}}} \right]$$

$$= \mathbf{j} \frac{\delta \Omega}{2} \left[1 + \frac{1}{1 + \frac{\delta \Omega}{\Omega_{\mathbf{I}}}} \right]$$

$$= \mathbf{j} \frac{\delta \Omega}{2} \left[1 + \frac{1}{1 + \frac{\delta \Omega}{\Omega_{\mathbf{I}}}} \right]$$
(2-11)

[†] It should be noted that $\delta\Omega$ has been used here to represent baseband radian frequency rather than Ω in order to prevent its unavoidable confusion with Im(s) in the present development.

whence, (2-8) becomes[†]

$$H_{BPP}(\Omega_{I} + \delta\Omega) = \prod_{k=1}^{K} \frac{p_{k}}{j\frac{\delta\Omega}{2} \left[1 + \frac{1}{1 + c_{1}\frac{\delta\Omega}{2}}\right] - p_{k}}$$
 (2-12)

clearly independent of IF radian frequency, $\Omega_{\rm I}$, and only a function of normalized baseband radian frequency $\delta\Omega$. It should be emphasized here that, in accordance to (2-9), $\Omega_{\rm I}$ is understood to be normalized by $\omega_{\rm C}$, the actual 3-dB lowpass cutoff radian frequency. As a consequence, the positive-frequency IF transfer function in (2-3) is given by

$$H^{\dagger}(f + f_{\underline{I}}) = H^{\dagger}_{\underline{BPP}}(\Omega_{\underline{I}} + \delta\Omega)$$
 (2-13)

provided that f and f $_{\rm I}$ are understood to be normalized by f $_{\rm C}$ = $\omega_{\rm C}/2\pi$. In order to minimize notational clutter in what follows, we will assume the following equivalences

$$\begin{cases}
\delta\Omega \sim \omega \\
\Omega_{\rm I} \sim \omega_{\rm I}
\end{cases}$$
(2-14)

and define the positive-frequency final IF transfer function referred to baseband as

$$H^{+}(\omega + \omega_{I}) \equiv \prod_{k=1}^{K} \frac{p_{k}}{j\frac{\omega}{2} \left[1 + \frac{1}{1 + c_{1} \frac{\omega}{2}}\right] - p_{k}}$$
 (2-15)

[†] The reader is reminded that Hppp, as used here, serves as a symbol. If taken as a legitimate function, it would be necessary to use different notation with each transformation, which could confuse matters rather than enhance understanding.

In modeling the practically-achievable design of a receiver's final IF filter, two important factors must be taken into account; namely, its bandwidth and center frequency deviations from those desired. Defining parameters

- c = bandwidth factor, around unity, equal to the ratio
 of actual-to-specified IF filter bandwidth
- c = center-frequency offset factor, around zero, that
 relates the IF filter's center frequency deviation
 as a fraction of the IF bandwidth

it is possible to rewrite (2-15) so as to include effects of design tolerances. It is not difficult to see that the effect of c_2 on ω is the inverse dilation ω/c_2 . On the other hand c_3 will give rise to the translation ($\omega-2c_3$), since the normalized IF bandwidth is 2. To a good first-order approximation, the combined effects of c_1 , c_2 , and c_3 on (2-15) are embodied in the modified expression that follows, where, again, H⁺ is used as a symbol.

$$H^{+}(\omega + \omega_{1}) \equiv \prod_{k=1}^{K} \frac{p_{k}}{j \frac{\omega - 2c_{3}}{2c_{2}} \left[1 + \frac{1}{1 + \frac{c_{1}(\omega - 2c_{3})}{2c_{2}}}\right] - p_{k}}$$
(2-16)

Note that when c_2 =1 and c_3 =0, (2-16) reduces to (2-15), which indicates no design errors. Typical 1% error implies that c_2 and c_3 would range over (0.99, 1.01) and (-0.01, 0.01), respectively. The consequence of such design variation will be a mismatching of antenna-port receivers, a condition that could tend to limit subsequent processing performance.

2.2.3 Normalization At RF

Another important system parameter is the fractional bandwidth at RF, which may be defined as

$$c_{ij} = \frac{2}{\omega_0} \tag{2-17}$$

where, again, 2 is the normalized bandwidth of the IF filter attributed to its associated lowpass prototype. In view of (2-4), (2-17) may be incorporated into (2-3) to yield an expression for the baseband channel transfer function with no explicit dependence on ω_0 . It should be noted here that ω_0 , as used in (2-17), is the RF center radian frequency normalized by $\omega_{\rm C}$, the actual 3-dB cutoff lowpass radar frequency.

Consider the exponential term within the summation of (2-3). Upon substituting (2-4) and (2-17) into this $^{\prime}$ n, we get

$$e^{j2\pi(f+f_0)\tau} \ell = e^{j\frac{\pi\ell d_0}{f_0}(f+f_0)\sin\theta}$$

$$= e^{j\pi\ell d_0(1+\frac{f}{f_0})\sin\theta}$$

$$= e^{j\pi\ell d_0(1+c_4\frac{\omega}{2})\sin\theta} \qquad (2-18)$$

since $f/f_0 = \omega/\omega_0$, in general. Including the effects of c_2 and c_3 in (2-18), (2-3) may be written, most conveniently, as a function of the normalized baseband radian frequency ω , as follows:

$$C(\omega) = \sum_{\ell=1}^{L} a_{\ell} e^{j\pi\ell d_0} \left[1 + c_{\ell} \frac{\omega - 2c_3}{2c_2} \right] \sin\theta H^{\dagger}(\omega + \omega_{I})$$
(2-19)

where, C is understood as a symbol and not a function.

In the above development we introduced four system parameters (in addition to the ones included in Section 2.1), two of which were instrumental in elminating the cumbersome explicit dependence of the baseband channel transfer function on actual IF and RF frequencies, leaving only the desired dependence on normalized radian frequency ω . In fact, we have shown that the baseband channel transfer function reduces to

$$C(\omega) = \sum_{\ell=1}^{L} a_{\ell} e^{j\pi\ell d_{0}} \left[1 + c_{k} \frac{\omega - 2c_{3}}{2c_{2}} \right] \sin\theta \quad \bullet$$

a conceptually-appealing and computationally-desirable form.

3.0 SIGNAL GENERATION PROGRAM

The development of the signal generation program, denoted by the acronym SIGGENC, is based on a discretized form of the normalized baseband channel transfer function, $C(\omega)$, as given in (2-20). An appropriate channel transfer function discretization, $\{C(\omega_i)\}_{i=1}^{-1}$, results from sampling $C(\omega)$ at a rate sufficiently higher than the Nyquist rate as dictated by the baseband transfer function of the IF filter, $H'(\omega+\omega_1)$. Applying an inverse discrete Fourier transform on $\{C(\omega_i)\}_{i=1}^{-1}$ gives a good approximation of its corresponding discrete complex-valued impulse response $\{c(t_i)\}_{i=1}^{-1}$. Then, a sampled noise-source channel input, $\{P(t_i)\}_{i=1}^{\infty}$ gives rise to a received sampled baseband channel signal $\{\zeta_{\underline{P}}(t_i)\}_{i=1}^{\infty}$, via the discrete convolution

$$\zeta_{B}(t_{j}) = \sum_{i=1}^{I} P(\tau_{i}) c(t_{j} - \tau_{i})$$
 (3-1)

According to previous discussion, a number of directionally-distinct sampled noise-source signals incident onto an antenna array will give rise to a received baseband port signal that is a superposition of sampled baseband signals received from each source through its associated discretized channel. More specifically, the sampled received baseband port signal is given by

$$\zeta_{BP}(t_{j}) = \sum_{k=1}^{K} \zeta_{E_{k}}(t_{j})
= \sum_{k=1}^{K} \sum_{i=1}^{I} P_{k}(\tau_{i}) c_{k}(t_{j} - \tau_{i})$$
(3-2)

where $\{P_k(t_i)\}_{i=1}^{\infty}$ is the noise sequence into the k-th channel associated with sampled impulse response $\{c_k(t_i)\}_{i=1}^{1}$ and k=1, 2, ..., K, the number of distinct channels.

SIGGENO is a structured FORTRAN IV computer simulation program designed to use (3-2) in order to generate received sampled baseband signals at the main and auxiliary ports of a multiport antenna system mentioned in Section 2.0 and described, in more detail, in Project Memorandum 8512-01. The discussion that follows provides a description of the particular modularized structure of SIGGENO, its execution and subsequent validation by means of a specific numerical example.

3.1 General Frogram Structure

Program SIGGENO has been developed with an emphasis on a structure which exhibits logical clarity, possesses inherent flexibility and lends itself to a natural and efficient growth. To begin with, all pertinent system specifications of the multiport signal generation problem at hand are relegated to a clearly readable table of parameters constituting an input data file, SIGGENO:D, via which the user may readily describe a variety of system situations of possible interest. In this sense, all pertinent system parameters that could potentially be varied have been removed from the executable part of the program.

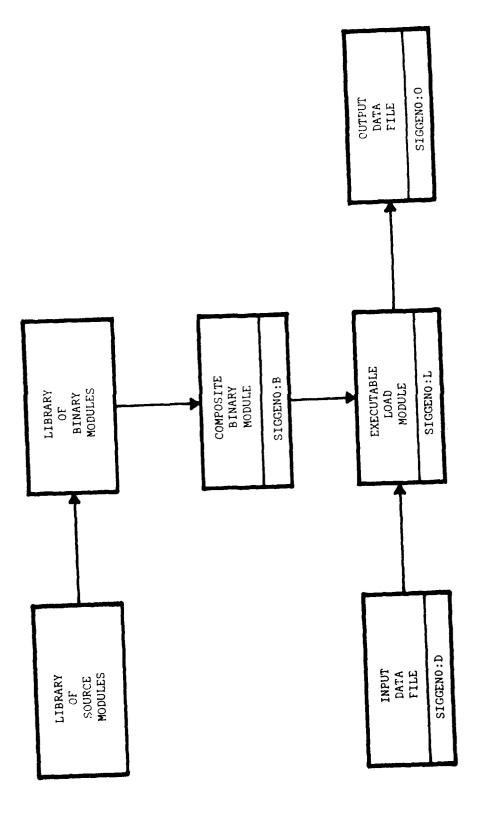
functional complete that it is in a generation problem as a whole, elementary functional complete that it is interested identified and corresponding well-commented subrouting a complete that it is interested written. The set of these source modules SIGTEN: , to be a complete that it is a complete in the form of distinct uncompled source file, the complete class bearing the suffix:S, the identifier for source. The complete class werein each module is identified by the suffix:B. A concatenation of the set of hinary modules results in the composite binary signal generation results, IGMENG:E. Subsequently, SIGGENO:B is converted to an executable signal generation load module, SIGGENO:L. Given input data file SIGGENO:I, which defines a multiport system situation to be examined, load module SIGGENO:L may be executed to produce an output file, SIGGENO:O, containing the input system specifications, receiver and channel spectral and time-domain characteristics, and, most importantly, the desired set of sampled baseband port signals.

The simplified block diagram of Figure 3-1 portrays the essence of the modular structure of program SIGGENO. Because of its special structure, the user has the flexibility of editing and augmenting a given source module without needlessly effecting any other. Following this, he may compile the augmented source module into its binary form, again without involving any other module. Finally, SIGGENO:B may be reconstructed and SIGGENO:L regenerated. The inherent efficiency of this approach is clear.

3.2 Specific Program Description

Included below are the specific elements that comprise the signal generation program SIGGENO. Assuming a five-port antenna array system, a complete listing of the associated input data file, SIGGENO:D, is given in the first subsection. The next subsection describes the modules that comprise the source library, gives a functional flow diagram of the program and provides complete listings of the subroutines involved. Following the construction of the library of corresponding binary modules, composite binary and load modules, SIGGENO:B and SIGGENO:L, are formed via appropriate job control language programs. Finally, the execution of load module SIGGENO:L with input data SIGGENO:D results in an output file SIGGENO:O.

In developing the mechanics of the present methodology, the authors have consulted with C. N. Sorg, G. L. Guenthner, and R. T. Short of Motorola's Engineering Computer Center.



General Modular Structure of Signal Generation Program SIGGENO Figure 3-1.

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3.2.1 Input Data File

The input data file that follows gives a complete parametric description of a five-port antenna system in accordance with the discussion of Section 2.0. Excluding print options at the top of the list, the parameters specified fall into three major categories. The filter parameters define the lowpass prototype filter, fractional bandwidths at IF and RF, normalized baseband radian frequency range and an initial radian frequency, number of frequency samples to be used and an optional parameter for choosing a baseband equivalent of a lowpass or a bandpass receiver filter. It should be noted that the latter option is consistent with choosing a receiver whose selectivity is determined by its final IF filter.

The channel parameters relate to the numbers of noise sources, or, equivalently, the channels corresponding to them, with respect to each antenna port. Each channel number is followed by related specifications of noise-source amplitude, initial setting of RANDU noise generator, time sample number at which the source has been turned on, subsequent periodic blink duration in time samples and angle of arrival in degrees. Note that, with RADRNG=4, the normalized time increment between samples is $2/\pi$.

The port parameters include the antenna separation factor d_0 , the number of port signal samples desired and, of course, the number of ports, chosen in the present case to be five. Under port "0" are included specifications of the main antenna port. In the present case, NEL=255 refers to the number of elements that comprise the main Taylor-weighted linear array and LOC1=1 indicates the number of the first element of the array with respect to a reference origin as shown in Figure 2-1. The subsequent two parameters are c_1 and c_2 , the bandwidth factor and the bandwidth offset factor as defined in subsection 2.2.2. Note that the remaining four ports describe similar parameters associated with the omnidirectional auxiliaries and their receivers. To be noted here is the fact that all receivers are matched. Any distortion among port signals, here, is mainly attributed to the frequency response of the main antenna sidelobe region at the precise angles of arrival specified.

3.2.2 Source Library and Program Architecture

The elementary modules that comprise the source library of the signal generation program SIGGENO are functionally described and classified according to category. Subsequently, the minimum-core architecture of the composite virtual source program, SIGGENO:S, is clearly demonstrated by means of a functional flow diagram. Finally, complete FORTRAN listings of all source modules are included for convenient reference.

3.2.2.1 Functional Description of Source Modules

A functional description of the individual source modules is given in the itemized list below.

SIGMAINO:S

- The main controlling program which calls auxiliary executive programs that perform specific tasks.

SPECIFICATION OF SYSTEM PARAMETERS

PRINT OPTIONS	<i>y</i>			
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FB1F -	FRACTIONAL BANDWIDTH AT FINAL IF	10000		
FBRF RADRNG =		2.00000	000	
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CHANNEL 2 :	AMPLITUDE OF NOISE SOURCE		00000	
N	FIRST-TIME-ON SAMPLE NUMBER HINK DURATION IN SAMPLES AZIMUTH ANGLES OF INCIDENCE (DEG)	1 100000	10000 00000	

CHANNEL 3 L	AMPLITUDE OF NOISE SOURCE		.00000
	SAMPLE NUMBER I IN SAMPLES		100001
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CHANNEL 4	AMBITATION OF MOTOR COMBCE	•	
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00	ANTENNA-ELEMENT SEPARATION FACTOR	1 1.00000	000
NS	OF SIGNAL SAMPLES	-	128
NPORTS -	NUMBER OF PORTS	••	S
PORTO :			
NEL	NUMBER OF ANTENNA ELEMENTS	••	552
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	NUMBER OF ANTENNA ELEMENTS	•• (→.
	LOCALION OF THE PLANT ELEMENT		→ 6
-	BANDWIDTH OFFSET FACTOR		00000
PORT2			
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PORT3 :			
	NUMBER OF ANTENNA ELEMENTS		~ !
BWFCTR -	LOCALION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTOR	000001 :	000

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••	
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BWOFF -	PORT4 6 NEL - LOC1 - BWFCTR -

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SIGSET:S

- The first auxiliary executive program designed to read and write from the input data file, SIGGENO:D, by means of special subroutines in accordance to preset formats. All data read is made available to SIGMAINO:S in identified common blocks.

PRTSGNLO:S

- The second auxiliary executive program called by SIGMAINO:S. This program uses the input data available in common and generates the desired port signals with the aid of a number of dedicated subroutines. As such, this program may be considered the central executive program in SIGGENO:S.

RW:S

- This is a dedicated subroutine designed to read and write an 80-character literal data string. No data is returned to the calling program SIGSETO:S.

RWID:S

- This is a dedicated subroutine designed to read and write a 60-character literal data string followed by numerical data within the next 20 spaces which are returned to the calling program, SIGSETO:S. The numerical data may consist of integer, decimal or complex scalar values.

ANTWT:S

- This is a dedicated subroutine designed to provide a Taylor weighting sequence for a linear array given the number of elements that comprise it.

FILTER:S

- This is a dedicated subroutine designed to generate a discretization of the baseband equivalent transfer function of either the final IF bandpass filter or a lowpass alternative. The number of frequency samples used is specified in SIGGENO:D.

AMPH:S

- This is a dedicated but optional subroutine that computes the amplitude and phase counterparts to a given transfer function. This subroutine could be used to graphically assess the frequency dependence of a main-antenna channel and its deviation from an auxiliary one.

IMPULS:S

- This is a dedicated subroutine designed to compute a sampled baseband impulse response from a sampled baseband transfer function.

FFT2:S

- This is a dedicated subroutine designed to compute the forward or inverse discrete Fourier transform of a complex sequence whose number of samples is a power of 2.

CHANNEL:S

- This is a dedicated subroutine which takes the antenna and receiver characteristics to compute a baseband transfer function associated with a particular angle of arrival of a specified noise source.

BLINK:S

- This is a dedicated subroutine whose purpose is to generate a discretized on/off switching function consisting of an appropriate sequence of 0's and 1's.

SIGNALO:S

- This is a dedicated subroutine which uses the on/off switching sequence in order to initially turn on and subsequently periodically blink an input noise sequence provided by a random number generator, specifically mechanized by the well-known utility subroutine, RANDU. SIGNALO:S subsequently uses this blinked noise sequence in order to produce a desired number of received baseband samples through its associated channel via discrete convolution with its impulse response. Such individual channel baseband signals are returned to PRTSGNLO:S where they are appropriately accumulated into composite baseband port signals.

From their brief descriptions given above, it is easy to see that the source modules may be classified under three prominent categories as indicated by the tree diagram in Figure 3-2. SIGMAINO:S is the main executive control module which delegates specific duties to the auxiliary executive modules, SIGSETO:S and PRTSGNLO:S. In turn, these two modules make use of a number of dedicated subroutines which form the third category of classification. Note that RANDU is only a utility module available from the Honeywell 560 library. As such, it is not considered as a legitimate source module but only shown for the purpose of completeness.

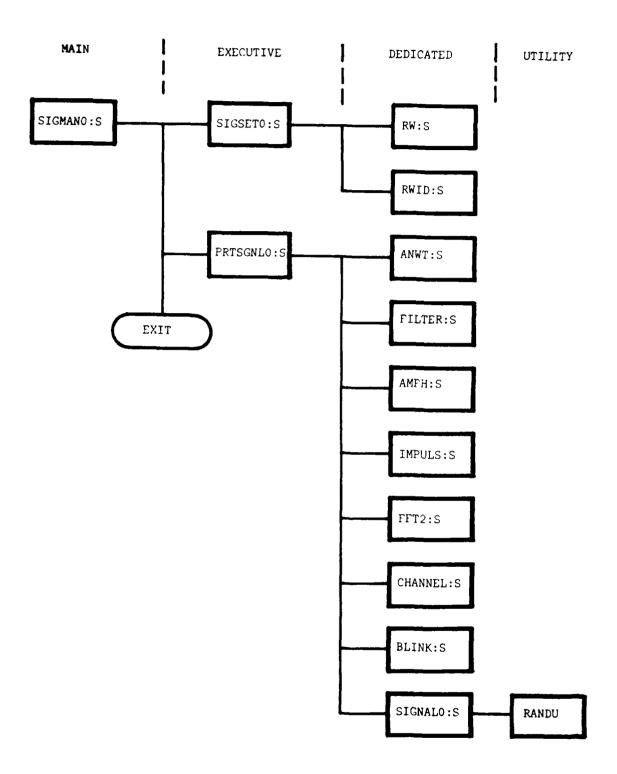


Figure 3-2. Tree-Diagram Category Classification of Modules Comprising the Signal Generation Source Libarary

3.2.2.2 Minimum-Core Program Architecture

The one module in the entire source library that could potentially account for the major part of the composite program's core requirement is PRTSGNLO:S. Having anticipated the need to keep core-requirement to a minimum, PRTSGNLO:S has been constructed appropriately. Given $N_{\rm n}$ noise sources and $N_{\rm p}$ ports, it is clear from its description that PRTSGNLO:S has been especially designed to generate one port signal array at a time by accumulating the $N_{\rm n}$ channel signal contributions. In so doing, the core-requirement is essentially determined by the current channel signal array storage and, of course, the storage of the port-signal array in question. As such, this minimum-core program architecture has the advantage of being independent of system dimensionality $N_{\rm n}$ x $N_{\rm p}$. Of course, the inevitable shortcoming of this approach is the need to recycle through the $N_{\rm n}$ noise sources and receiver transfer characteristics for each port signal computation of a condition which will tend to increase program execution time by some fraction of $N_{\rm n}$ x $N_{\rm p}$.

This minimum-core signal generation program architecture is clearly demonstrated in the functional flow diagram of Figure 3-3. Note that the key to keeping core at a minimum is the use of single utility arrays for temporarily storing current values of the receiver and channel transfer functions, the channel impulse response, the incident noise sequence, the channel baseband signal and its appropriate accumulation into the baseband port-signal.

3.2.2.3 FORTRAN Listings of Source Modules

Complete FORTRAN listings of the source modules of the signal generation source library are included here for easy reference. In writing each module, a sincere attempt has been made to make it almost self-explantory by including functional description, a complete list of definitions of input and output parameters and appropriate comments throughout the program, as necessary.

In the same sense that SIGGENO is the generic name of the present signal generation program and SIGGENO:S is the composite collection of source modules, the suffix:S has been left out from all subroutine names, as the reader will note. Included in the heading of each subroutine is the name of the source module, its date of origin and latest revision date. This minimal identification along with authors' names allows a general user to remain current with the program development and consult with the informed individuals in case of questions or problems.

3.2.3 Binary Library

Using a general but rather simple job control language program, JCL:B, compiled versions of the signal generation modules have been created. Carrying identical names but distinguished by the identifying suffix:B, the collection of these binary modules forms a binary library which complements the original source library.

Of course, the experienced computer user is well aware that a compiled binary version of a working program avoids the need of undesired repeated compilation during each execution. Clearly, a modular formulation of a large program offers the added advantage that an augmentation of any one source module will mean the recompilation of only that source module and not the entire program.



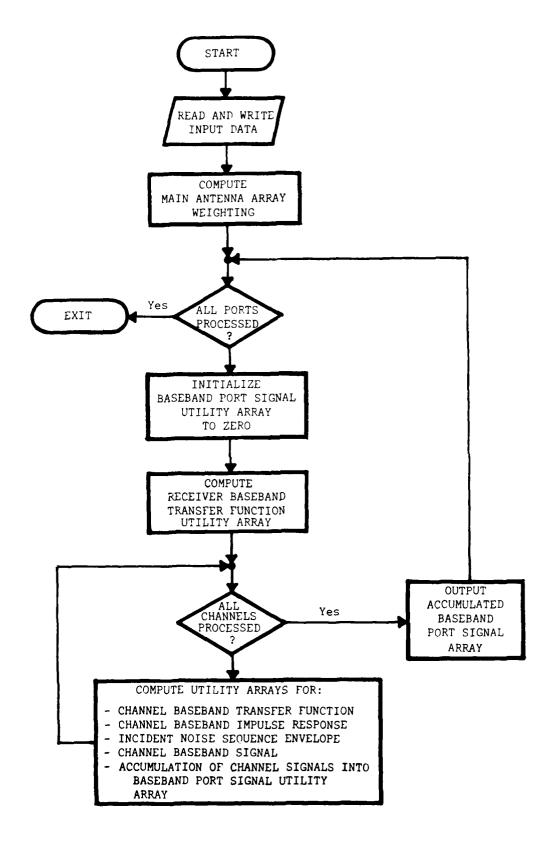


Figure 3-3. Functional Flow Diagram of the Minimum-Core Signal Generation Program SIGGENO.

BWFCTR(11) . BWOFF(11) . DO. NEL(11) . LOC1(11) . NPORTS. NS MOTOROLA GOVERNMENT ELECTHONICS DIV. POL (6) "FBIF" FBRF" RADRNG-RADIN-DRAU-NPOL-LPBP.NF AN(10) "TH(10)" 1X0(10)" N1(10)" NB(10)" NCHNLS I. M. KERTESZ RADAR SYSTEMS ANALYSIS GROUP SIGENOIS COMPUTATION OF COMPLEX BASEBAND SIGNALS CUNNECTEU TO SPECIFIED LINEAR ARRAYS TEMPE. ARIZONA 85282 AT MULTIPLE RECEIVER PORTS APRIL 19, 1980 1, 1980 S. M. DANIEL GENERATION PROGRAM SIGNIVOIS 7777 INR. INC. INSC 8 PREPAMED URIGINAL **REVISION** SIGNAL PROGRAM COMMON /SETO/ COMMON /SET2/ COMMON /SET3/ COMMON /SET1/ PHISGNIO CALL SIGSETO COMPLEX POL EXIT CALL CALL 9. 765. .01 20. 22. 23. 23. 25. 10. •

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IF(IWSC.EQ.0) GOTO 4000
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WRITE(108,300)
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WRITE(108,200)
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WRITE(108,200)
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WRITE(108,200)
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MOTURULA GOVERNMENT ELECTRONICS DIV.
                                                                                                                                                        NUMBER OF ELEMENTS IN LINEAR ARRAY
                                                                                                                                                                  LOCATION (NUMBER) OF FIRST ELEMENT
                                                                                                                                                                                                                                                FORMATIZOX, TAYLOR WEIGHTING FOR MAIN ANTENNA ARRAY. , / , 20X
                             COMPUTATION OF LINEAR ANTENNA ARRAY TAYLOR WEIGHTING
                                                                                                                                                                                           ARRAY ELEMENT WEIGHTING
                                                                                                                                   TEMPE. ARIZONA 85282
                                                                APRIL 19, 1980
                                                                           11, 1980
                                                     ANTETIS
                                                                                                                                                                                                                                                                                                                                                                                                                       (AL (I) . I=1 .NEL)
                                                                            JUNE
       SUBROUTINE ANIWI (NEL . LOCI . AL)
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                                                                                                  9
                                                                                                                                                                                                                                                                                                                                                                          AL (1)=1+0.5+CUS (ARG)
                                                                                                                                                                                                                                                                                                                                                               ARG=CON1 + (LOC-CON2)
                                                                                                                                                                                                                                      FORMAT (1X+79(*-+))
                                                                                                                                                                                                                                                                                 DATA PI/3.1415965/
                                                                                                PREPAMED
                                                                          REVISION
                                                               ORIGINAL
                                                                                                                                                                   LOCI
                                                                                                                                                                                                                                                                                                                  CON2=0.5+ (NEL+1)
                                                     PROGRAM
                                                                                                                                                                                                                DIMENSION AL(1)
                                                                                                                                                                                                                                                                                                                                                                                                                       WRITE (108,400)
                                                                                                                                                                                                                                                                      FORMAT (8F 10.5)
                                                                                                                                                                                                                                                                                                                                                                                     WRITE (108,100)
                                                                                                                                                                                                                                                                                                                                                                                                            WRITE (108.300)
                                                                                                                                                                                                                                                                                                                                                                                                                                  #RITE (108,200)
                                                                                                                                                                                                                                                                                                                                                                                                WRITE (108,200)
                                                                                                                                                                                                                                                                                                                                         DO 10 1=1+NEL
                                                                                                                                                                                                                                                                                                                             CON1 #PIZ/NEL
                                                                                                                                                                                                                            FORMAT (1H1)
                                                                                                                                                                                                                                                                                                         LOC=LOC1-1
                                                                                                                                                                                                                                                            -,39(1-1))
                                                                                                                                                                                                                                                                                                                                                    LOC=LOC+1
                                                                                                                                                                                        OUTPUT :
                                                                                                                                                                                                                                                                                              PI2=2*PI
                                                                                                                                                                                                                                                                                                                                                                                                                                             KETURN
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U		FERRESHER SERVERSES
00000	C SERREBEREBEREBEREBEREBEREBEREBEREBEREBER	EESHKERFEERENSEE LED TRANSFER FUNCTI S EQUIVALENT
OO	PROGRAM : FILTERIS	
ပပ	C REVISION : JUNE: 23, 1980	
00000	C PREPAMED BY I S. M. DANIEL & I. M. KERTESZ C MADAR SYSTEMS ANALYSIS GROUP C MOTOROLA GOVERNMENT ELECTHONICS C TEMPE, ARIZONA B5282	M. KERTESZ SIS GROUP ELECTMONICS DIV. B2
U U	NOTE::::::::::::::::::::::::::::::::::::	SAMPLES
Ų	UMAD - NORMALIZED RADIAN FR	REQUENCY INCREMENT
ں ں	C RADIN - INITIAL RADIAN FREQUENCY C FEIF - FRACTIONAL BANDWIDTH AT FINAL	JENCY H AT FINAL IF
ပ	d847	
υL	C C C C C C C C C C C C C C C C C C C	
ں ر	BWFCTH - BANDWI	
U	BWOFF - BANDWIDTH OFFSET	FACTOR
ပ	NPOL	
U (C POLE LOCATIONS	
ں ر	C OUTPUT : H - SAMPLED TRANSFER FUNCTION	ACT I ON
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JUU	C ADJUST INCREMENT AND INITIAL RADIAN FREQUENCY C COMPUTE SAMPLED THANSFER FUNCTION	j.
ပ	•	
	DRADL=0.5*DRAD/BWFCTK RADI=(HADIN/2-BWOFF)/BWFCTK-DRADL	
	UO 10 Imione Kauhkaui+Imukaul	
	1(1)#]	

111-31

	i	SUBROOT INE	KOR CHAN	NEL INGL		SCHOOLINE CARNEL (NEL-LOLI-AL-DO-LA-NADIN-DA-DA-DA-DA-DA-A-A-A-DA-DA-DA-DA-DA-DA-
PROGRAM ORIGINAL INPUT INPUT INPUT INFL IN		EVALUATION	H H H H H H H H H H H H H H H H H H H	ALIZEU AT DISC	H I W	INDEPENDENCE BERNESSESSESSESSESSESSESSESSESSESSESSESSESS
PREPAMED BY : INPUT : NEL LOCI AL IMPUT : NEL IMPUT : NE BWOFF FWHF HW DIAD OUTPUT : H BEREFEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	-	PROGRAM ORIGINAL	۷ ۲ ۲ ۲		CHANNELIS MAY 4, 1980 JUNE 26, 1980
INPUT : NEL LUCI AL INPUT : NEL IN	00000		PREPAHE		••	DANIEL & 1. P SYSTEMS ANALYS! LA GOVERNMENT E ARIZONA 85283
LUCI AL IN	ს ს	INPUT	. NEL		i.	NUMBER OF ELEMENTS IN LINEAR ARRAY
AL IN POLAD BAFCTR BADIN BAFCTR BADIN BAFCTR BADIN BAFCTR BADIN BAFCTR BADIN BATCTR BADIN S-BWO PDSTHEP I + DU+SIN(TH+PI/180	U) 	707	1		LOCATION (NUMBER) OF FIRST ELEMENT
NF RADIN DHAD BHFCTR BHNFCTR BHNFCTR HH DOUTPUT 8 HH DOUT	۰		A.			ARRAY ELEMENT MEGHTING
RADIN DHAD DHAD BHFCTR BWOFF FBHF FBHF COMPLEX HR.H.CH DIMENSION HR(1).H(1).AL(1) UATA PI/3.14159265/ HATIO=FBHF/BWFCTH DRADL=HATIO=DHAD/2 HADI=1+RATIO=FADIN/2-BWO) PDSTH=PI-DU-SIN(TH-PI/180	<u>ں</u> ر		E 4		. 1	AZIMUTA ANGLE TURGY OF INCIDENCE
DHAD BHFCTR BHOFF FUND BHCTR BHOFF FUND BHOFF BHOF	ى ر		Q ▼ &	Z		INITIAL MADIAN FREUENCY
BMFCTR BMOFF HH OUTPUT : H BMREHERERERERERERERERERERERERERERERERERER	ن د		DKA DKA			NORMALIZED RADIAN FREQUENCY INCREMENT
# #	, U		20	CIR		BANDWIDTH FACTOR
# #	U		3	ند.	•	FACTOR
M M	U		FBH	La.		FRACTIONAL BANDWIDTH AT RF
M M	U		Ĩ			RECEIVER SAMPLED THANSFER FUNCTION
# #	٠		20		•	ELEMENT SEPARATION FACTOR
M M	ں ں	OUTPUT	I			CHANNEL SAMPLED TRANSFER FUNCTION
).AL(1) /2-BWOFF) PI/180)		COMPLEX	2.20・11・12	14 17 16 16 16 16 16	ii W	化多氯甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基
//2-BWOFF)		DIMENSI	ON HR (1)	•H(1) •A		
DRADL=HATIO+DHAU/2 HADI=1+RATIO+(HAUIN/2-BWOFF)-URADL PDSTH=PI+DU+SIN(TH+PI/180)		NATA PE	/3.14159 BHF/BWFC	265/ TR		
		DRADL HK KAD1 = 1 •	A110*0KA RA110*(R	0/2 AUIN/2- (TH*PI/	18 E	DFF)-URADL
	ں				į	

44. DO 10 1=1.NF 45. RAD=RAD1+1*DRADL 46. CH=0 47. LOC=LOC1-1 48. LOC=LOC+1 49. LOC=LOC+POSTH*RAD 50. CH=CH+AL(J)*CMPLX(COS(ARG)) 51. ZO CH=CH+AL(J)*CMPLX(COS(ARG)) 52. 10 H(I)=CH*HR(I) 53. C RETURN 54. RETURN

III-33

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ŭ				が出来る。 2017年 - 2017年
		EVAL	EVALUATION OF	OF AMPLITUDE AND PHASE
، ن د		COMP	LEX SI	COMPLEX SAMPLED THANSFER FUNCTION
u u		PROGRAM	_	SHPHIS
ن د		ORIGINAL	_	APRIL 19, 1980
o O		HEVISION		-
00000		PREPAHED	 ⊱	S. M. DANIEL & I. KEHTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTHONICS DIV. TEMPE, ARIZONA BS282
i uuu	INPUT	IZ		SAMPLED TRANSFER FUNCTION NUMBER OF FREQUENCY SAMPLES
ပပပ	OUTPUT :		• •	
ii 001	COMPLEX H COMPLEX H DIMENSION FORMAT (1X.	COMPLEX HEREN HEREN HEREN HEREN HE COMPLEX H DIMENSION H(I) • AM(I) • PH(I) FORMAT(IX • 79)	(1) •Pt	
9 9 9 0 0 9 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	FORMAT (3)	JX PHASE	100E	FORMAT (35%, AMPL 1100E',/,35%,9('-'),/,(8f 10.5), FORMAT (37%, PHASE',/,37%,5('-'),/,(8f 10.5))
i UU	COMPUTE	COMPUTE AMPLITUDE AND PHASE	ANC	OMPUTE AMPLITUDE AND PHASE
i 	DO 10 1=1.NF AM(1) =CABS(H PH(1) =ACUS(R IF(AIMAG(H(1	DO 10 1=1.NF AM(I)=CABS(M(I)) PH(I)=ACUS(REAL(H(I))/AM(I)) IF(AIMAG(H(I)).LT.0) PH(I)=-PH(I	(1)	
t U	WRITE(108,100) WRITE(108,200) WRITE(108,100) WRITE(108,300) WRITE(108,100) RETURN	į	(AM(I), IH1,NF)	(AM(I),IMI,NF)

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11:	ں ں				ğ	FPA	PREPAKED	>	•	PROF. P. RANSOM & S.	S. M. DANIEL
13.	v			•	•	: ;				ENGINEE	ING DEPARTMENT
16.	ပပ									UNIVERSITY OF ILLINOIS CHAMPAIGN-URBANA, ILLINOIS	01S _Linois
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17.	υU		INDON!		••	×			•	AUXILIAMY REAL ARRAY WHOSE DDD AND EVI NUMBERED ELEMENIS ARE THE REAL AND THE	T WHOSE ODD AND EVEN- E THE REAL AND THE
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22.	ں ر					-	نية ا		•	FOUNTER TRANSFURM OPTION	710N
23.	ن ر									-1 : FOREWAND DFT	
25.	ں ر									TUNENSE	
26.	U (OUTPUT	_		×	; ;			TRANSFORMED AUXILIARY ARRAY	
24. 28.	ပ	M M M	OINENSION X(2)		i Z	# ~ X			# # #	化分类形式 医动物性动物 医甲状腺素 医甲状腺 医甲状腺 医甲状腺 医甲状腺 医甲状腺 医甲状腺 医甲状腺 医二乙二二乙二二二二二二二二二二二二二二二二二二二二二二二二二二二二二二二二	III III III III III III III III III II
29.			DATA P1/3.14159265/	3	3.	1	265	759			
٠ و			P12=2+P1	٠	- i	ž	XX4ZHZXX +	X			
31.			THIYNS	7	17	- ×	֝֞֞֓֓֞֓֓֞֜֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֡֓֓֓֓֓֓֓֡֓֓֡֓֡֓֡֡֡֓֜֓֡֓֡֓֡֡֡֡֓֡֡֡֓֜֡֓֡֡֡֡֡֡	TACOMI T XNOT		UNATEL F IF(IT-EEG-I- UNATEL-UNAF No 10 1ml.nx 1 (MOSHMOD(I-1.0) 1 10m0m1 2 10m	- C. W. W. C
33.			FCTR	SR		\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	: : : : : : : : : : : : : : : : : : :	500	F.C.	NX I	1 ; j ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ;
*			X (12)	17	J.	114	X (1.	2M1)	-	X(IZMI) BFCTR*X(IZMI) X(IZ) BFCTR*X(IZ)	
35.	9		CONTINUE	<u>S</u>	401						
36.			1=5	•	•	3	5		•		
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900			ATREX (C) ATTEX (CP) 1		-	×	X	, do ,	2 ~	(IdI) XH(Idr) X + (I) XH(r) X	CTAT:
•			X(I)=XTH	X	~	×	17.1	R X(IPI)=XI	. 🗕		
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ISE+XLXE+(XSE+I)+IEHIE : ISE+IE+(XSE+I)+XEHXE : XEHXLXE DO 50 I#1,NX \$ IMUD#MOD(I=1,2) \$ IF(IMOD.EQ.0) 60T0 50 I1#2*I-1 \$ I2#I1+1 \$ X(I1)#-X(I1) \$ X(I2)#-X(I2) CONTINUE MXTREERGAX(U)-EIAX(UPL) & MXTIFERAX(UPL)+WIAX(U) X(U)=X(I)-EXTR & X(UPL)+X(IPL)-EXTI ISTEPEZ*KMAX I THEIF*PIZ/KMAX I STHESIN(TH/2) MSRa-2+SIH++2 # WSI#SIN(TH) # WREL # WIRO X(I)=X(I)+WXTH # X(IPI)=X(IPI)+WXTI CHICKMAN I UPLECOL I IPLEIOL IF (KMAK-NX2.6E.0) GOTO 4000 KMAX=1STEP # 6010 3000 UO 30 18K NXZ ISTEP DO 40 KELSKHAX.2 CONTINUE CONTINUE CONTINUE KEAXED RETURN とうまつ 3000 4000 20 50 30 0 40. 51. 52. 53. 54. 57. 58. 59. 900 **44 45** 47. 48. •6 50. 56. 61. 62. 63.

CALLEGATE

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S. M. DANIEL & I. M. KERTESZ
RADAR SYSTEMS ANALYSIS GRUUP
MOTUROLA GOVERNMENT ELECTRONICS DIV.
                                                                                                                                                                                                                                                 FORMAT(32x, 1MPULSE RESPONSE 1,/, 32x, 16(1-1),/, (8F10.5))
                                                                                                                                                      NUMBER OF FREQUENCY SAMPLES
                                                                                                                                                                SAMPLED THANSFER FUNCTION
                            EVALUATION OF SAMPLED IMPULSE RESPONSE
                                                                                                                                                                                    COMPLEX IMPULSE RESPONSE
                                       FROM A SAMPLEU TRANSFER FUNCTION
                                                                                                                                  TEMPE. ARIZONA 85262
                                                                                                                                                                                               AUXILIARY REAL ARRAY
                                                                      MAY 11. 1980
                                                                                JUNE 7. 1980
           SUBROUTINE IMPULS (NF. H. X. HIMPL. IV)
                                                            IMPULSIS
                                                                                                                                                                                                                                                                                                                                                                                                         WRITE(108,200) (HIMPL(I).Iml.NF)
WRITE(108,100)
                                                                                                                                                DIMENSION H(1) .HIMPL(1) .X(1)
                                                                                                                                                                                                                                                                                                                                                                            HIMPL(I)=CMPLA(X(I1)+X(I2))
                                                                                                                                                          •
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                                                                                                                                                                                                                                                                                                                           (CHI) H) SYMIY = (I+I) X
                                                                                                                                                                                                                                                                                                                                                                                      (F(IM.EQ.0) RETURN
                                                                                                                                                                                                                                        FORMAT (1X+79("-")
                                                                                                                                                                                       HIMPL
                                                                                                                                                                                                                                                                                                                                              CALL FFT2(X,NF,1)
                                                                                                       PREPAMED
                                                                                                                                                                                                                                                                                                                                                                 12=2+1 + 11=12-1
                                                                                  REVISION
                                                                                                                                                                                                                                                                                                                X(I) BREAL (H(IM))
                                                                       ORIGINAL
                                                                                                                                                                                                                                                                                                      DO 10 1=3.NF2.2
                                                             PROGRAM
                                                                                                                                                                                                                       COMPLEX HOHIMPL
                                                                                                                                                                                                                                                                                                                                                                                                  MRITE (108-100)
                                                                                                                                                         Ž I
                                                                                                                                                                                                                                                                                                                                                        DO 20 I=1.NF
                                                                                                                                                                                                                                                              NF2=2*NF
                                                                                                                                                                                                                                                                                                                                      OUTPUT
                                                                                                                                                                                                                                                                        X (1) #0
                                                                                                                                                                                                                                                                                  X (2) =0
                                                                                                                                                                                                                                                                                                                                                                                                                               RETURN
                                                                                                                                                                                                                                                                                              Z=1
                                                                                                                                                                                                                                          200
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6		SUBROU	I INE	BL INK (N	17 • NG	PN H	SUBROUTINE BLINK (N) NB+NF+NS-IBLNK)
.				ON/OFF	PE	0011	ON/OFF PERIODIC BLINK CONTOL GENERATOR
	U U		020	PROGRAM		••	BLINKIS
:	Ü		ORI	ORIGINAL		-	JUNE 12. 1980
60	o o		REV	REVISION		-	JUNE 16, 1980
• •	ט ט		PRE	PREPAKED	₽¥	••	I. M. KERTESZ & S. M. DANIEL
11.	Ü						HADAR SYSTEMS ANALYSIS GROUP
12. 13.	ပပ						MUTUROLA GOVERNMENT ELECTRONICS DIV. TEMPE. ARIZONA 85282
14.	: 	INPUT	-	72			FIRST-TIME-ON SAMPLE NUMBER
16.	· U) 		Ð			BLINK DURATION IN SAMPLES
17.	v			ż			
18.	y (S		ı	NUMBER OF SIGNAL SAMPLES
20.	U U	OUTPUT	••	IBLNK			BLINK CONTROL ARRAY HAVING (NS+NF/2)
22.					N N	**	
23.		DIMENS	I NOI	DIMENSION IBLNK(1)			
24.		J)*1					
25.		72=0	,				
26.		Z-74-14-2 20 00 14-2	Z - 7 - 7 - 7 - 7 - 7 - 7 - 7 - 7 - 7 -	1 # 1			
28.	10	18LNK (1) #0	1)=0	! •			
29.		017					
30.		NSPHENS+NF/2	S+NF/	~			
3. 3.		DO 20 INNINSPH	· I N I	NSPH			
32.		I BI NK (I) B. I]	100.1				
, 4°		1F (MUD	C.SB	IF (MUD (J.NB) .NE.U) GUTO	50		20
35.		J3×J2					
36.		J2#J1					
• • •	00		911				
96	2	NAUT PE	7				
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•	v	1 JUNE 8.
10.	ပ	MEVISION : JUNE 23. 1980
11.	ပ	
12.	U (· I · N·
• • • •	, ر	
. 5.	ں ر	TEMPE ARIZONA BSZBZ
9	Ų	
17.	ں ا	INPUT : XIMPL - COMPLEX BASEBAND SAMPLED IMPULSE
18.	ر د	
19.	ں ا	- NUMBER OF SAMPLES IN XIMPL
20.	υ (NOISE
71.	ى ر	- NX-ELEMENI SLIDING-WINDOW
23.	ں ر	•
24.	ں ر	OUTPUT : S - NS-ELEMENT HECEIVED COMPLEX BASEBAND
25.	ပ	SAMPLED SIGNAL ARRAY
26.	ပ	
27.		COMPLEX XIMPL+S
28.		DIMENSION XIMPL(1) .P(1) .S(1) .IBLNK(1)
62		ZXXZHIXZ
90.		
•10		
32.		2×1 m 1 m 2 m 2 m 2 m 2 m 2 m 2 m 2 m 2 m
• • • •	-	
• 4	•	
36		ANTIGORNAL CO
• •		
• • •		CALL MANDO(1X+1X+0.)
• :	ć	(C-0-17) (DI) (MI) (MI) (MI) (MI) (MI) (MI) (MI) (M
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•		727417 37 72 72 72 72 72 72 72 72 72 72 72 72 72
•1•		>= (1)
• • • • • • • • • • • • • • • • • • •	•	C. T. C. T. D. C. T. C.
•	>	10-1-1-10-1-1-10-1-1-10-1-1-10-1-1-1-10-1

no 50 J=l•NXM1 50 P(J)=P(J+l) Call Ranuu(IX•IY•2) P(NX)=IBLNK(IB)*(2-0.5) 30 IB=IB+l RETURN END

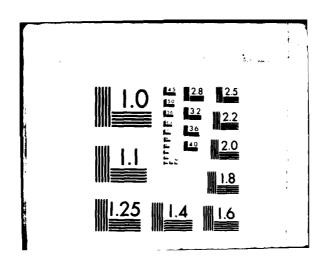
> 46. 45. 47. 49.

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Fig. 1. St. W. W. C.

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                                                                                                                                                      MOTUROLA GOVERNMENT ELECTRONICS DIV.
                                                                                                                                                                                                                                                           CX & RX
                                                                     A COMPLEX. REAL OR INTEGER SCALAR VARIABLE VALUE
                                                                                                                                  S. M. DANIEL & I. M. KERTESZ
HADAR SYSTEMS ANALYSIS GROUP
                                                                                                                                                                                                                                       9
                                                                                                                                                                                                                                                          9
                                                                                                                                                                                                                                                                     READING AND WRITING AN 80-CHARACTER LINE
                                                                                                                                                                                              READ & WRITE INTEGER
READ & WRITE HEAL
READ & WRITE COMPLEX
                                                                                                                                                                                                                                       COMPLEX SCALAR EXCLUSIVE
                                                                                                                                                                                                                                                HEAL SCALAR EXCLUSIVE OF INTEGER SCALAR EXCLUSIVE
                                                                                                                                                                            TEMPE - ARIZONA 85282
                                     CONSISTING OF
A 60-CHARACTER COMMENT
                                                                                                                                                                                    OPTION INDICATOR
                                                                                                   APRIL 19, 1980
                                                                                                             15, 1980
                                                                                                                                 S. M. DANIEL
                                                            AND
                                                                                          REIDIS
        SUBROUTINE RWID (CX+RX+IX+IND)
                                                                                                              JUNE
                                                                                                                                                                                                                                                                                                                                         READ (105+100) ARIS+1X+AR3
                                                                                                                                                                                                                                                                                                                                                   WRITE(108.100) AHIS. [X.AR3
                                                                                                                                                                                                                                                                                                                                                                                 HEAD (105,200) AR15, HX, AR3
                                                                                                                                                                                                                                                                                                                                                                                           WRITE(108,200) AHIS, HX, AR3
                                                                                                                                                                                                                                                                                        UIMENSION ARIS(15).AR3(3)
                                                                                                                                                                                                                                                                                                                     FORMAT (15A4,2(F8,5,2X))
                                                                                                                                                                                                                                                                                                                                IF (IND.NE.0) GOTO 1000
                                                                                                                                                                                                                                                                                                                                                                       IF (IND.NE.1) GOTO 2000
                                                                                                                                                                                                                                                                                                                                                                                                                READ (105,300) AR15,CX
WRITE(108,300) AR15,CX
                                                                                                                                                                                                                                                                                                           FORMAT (1584.F8.5.384)
                                                                                                                                  8
                                                                                                                                                                                                                                                                                                   FORMAT (15A4, [8,3A4)
                                                                                                                                  PREPAKED
                                                                                                              SEVISION
                                                                                                   ORIGINAL
                                                                                         PROGRAM
                                                                                                                                                                                     XX
                                                                                                                                                                                                                                                                             CUMPLEX CX
                                                                                                                                                                                                                                                                                                                                                               RETURN
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AD-A109 927 UNCLASSIFIED	AUG 81 5 M D	TEMPE AZ GOVE NCE RELAXATION ANIEL, I KERTE	SZ	ONICS DIV VE PROCESSING.(U) F30602-A0-	F/G 20/14 -C-0031 NL
2 or 7 8 ₅₀₀ .					



3.2.3.1 Creation of Binary Modules

The specific job control language program, JCL:B, written for the purpose of creating a binary version of a given source module is listed below.

Individual Binary Module Generation Program JCL:B

- 1 1.000 IJOB 298.DANIEL (8512),7.8LDG90
- 2 2.000 ILIM11 (TIME+1)+(UU+1)+(CU+16)+(ACCUUNT)
- 3 3.000 ISET MISI/NAMEISIINISAVE
- 4 4.000 ISET MIBO/NAME: BIOUTISAVE
- 5 5.000 [FORTHAN LS+NS+UC+S1+B0

Given a specific module to be processed, this program is batched with a name substitution command; e.g.,

! BATCH JCL:B 'NAME' = SIGMAINO

As such, JCL:B is completely general.

3.2.3.2 Composite Binary and Load Modules

Given the set of signal generation binary modules, it is an easy matter to form a composite signal generation binary module which is logically identified by the name, SIGGENO:B. The specific JCL program that actually accomplishes this is called JCLSIGO:BL. Clearly, the first letter of the suffix :BL refers to the creation of the composite binary module, SIGGENO:B. The second letter denotes the additional generation of the associated executable load module, SIGGENO:L, which is included here strictly for convenience.

The complete listing of JCLSIGO:BL is given below. Note that by virtue of the special form of this

Composite Binary and Load Module Generation Program JCLSIGO:BL

- 1 1.000 JJOH 298. DANIEL (8512) . 7. BLDG90
- 2 2.000 | LIMIT (TIME+1) + (UU+2) + (CU+16) + (ACCOUNT)
- 3 3.000 IPCL
- 4 4.000 COPY AMPHIB OVER SIGGENOIB
- 5 5.000 COPY ANTWTIB
- 6 6.000 COPY BLINKIE
- 7 7.000 COPY CHANNELIB
- 8 8.000 COPY FFT2:B
- 9 9.000 COPY FILTERIB
- 10 10.000 COPY IMPULSIB
- 11 11.000 COPY PHTSGNLUIU
- 12 12.000 COPY RWIB

- 13 13.000 COPY RalD:B
- 14 14.000 COPY SIGMAINU:B
- 15 15.000 COPY SIGNALUIB 16 - 16.000 COPY SIGSETUIH
- 17 17.000 ILYNX SIGGENUIB OVER SIGGENUIL

JCL program, all binary modules that comprise the composite one may be listed alphabetically, thus forming a convenient list for easy reference. To execute this program, the simple batch command !BATCH JCLSIGO:BL is used.

3.2.4 Program Execution

The execution of the load module, SIGGENO:L, is carried out by means of a specially designed JCL program shown below.

Execution Program JCL:EX

- 1 1.000 IJOB 298.DANIEL (8512).7.8LDG90
- 2 2.000 ILIMIT (TIME+1)+(UO+50)+(CO+16)+(ACCOUNT)
- 3 3.000 ISET F:108/NAMLIU
- 4 4.000 IRUN (LMN.NAME:L)
- 5 5.000 IDATA
- 6 6.000 IEXEC NAME:D

As is the case of JCL:B, the present program is of general use, in the sense that the name of the generic program may be defined in the batch command

! BATCH JCL:EX (E) 'NAME' = SIGGENO

Other important program features of JCL:EX include the reading from the input data file SIGGENO:D and creation of the output file SIGGENO:O. Here, suffices:D and:O denote data and output, respectively. An additional important feature of JCL:EX is that it allows for multiple simultaneous runs with augmented SIGGENO:D data. This is because the current version of SIGGENO:D is buffered at each batching.†

3.2.5 Output File

The output file generation from a specific program execution involving one channel and four ports is listed in the pages that follow. In addition to the parametric system description from SIGGENO:D, SIGGENO:O includes the main antenna array weighting, receiver and channel frequency and time domain characteristics, individual channel and port signals. Figure 3-4 compares representative main and auxiliary baseband channel amplitude responses. Although the asymmetry of the auxiliary response is barely noticeable, that of the main is rather pronounced. Of course, based on previous discussion, this expected effect is due to the aperture dispersion of the main array.

It should be noted that if the three print options in the table of system specifications were set to "0," the printing of receiver and channel characteristics along with associated channel signals could be conveniently suppressed. The BCR adaptive processing that will follow will need only main and auxiliary port signal information.

It should be noted that the JCL programs presented here are peculiar to Motorola's Honeywell CP-V engineering computer. They are included here to clarify fully the methodology behind the signal generation software. Similar programs may be generated for other computers, with appropriate changes, as needed.



SPECIFICATION OF SYSTEM PARAMETERS

PRINT OPTIONS			
	RECEIVER CHARACTEMISTICS	•	
IAC -	CHANNEL CHARACTERISTICS	-	
1826	INDIVIDUAL CHANNEL SIGNALS	-	
FILTER PARAM	PARAMETERS		
NPOL	NUMBER OF LOWPASS PROTOTYPE POLES	-	
		1 70700	70700
5016		00202-	.70700
FBRF	FRACTIONAL BANDELDTE AT FINAL IT		
RADRNG -		00000	
RACIN	NURMALIZED INITIAL RADIAN FREQUENCY	00000-2- 1	
N.	NUMBER OF FREQUENCY SAMPLES	32	
- 686	LOWPASS/BANDPASS UPTION		
	O : LOWPASS	•	
	1 : BANUPASS		
3 . i	METERS		
NCHNLS -	NUMBER OF CHANNELS PER PORT	•	
CHANNEL 1 1			
N	AMPLITUDE OF NOISE SOURCE	1 00000	
- 0XI	INITIAL MANDU SETTING	-	
- Z	FIRST-TIME-ON SAMPLE NUMBER	-	
9 2	SAMPLES	10000	
H	AZIMUTH ANGLES OF INCIDENCE (DEG)	1 45.00000	
CHANNEL 2 1			
Z	AMPLITUDE OF NOISE SOURCE	00000.	
- 0XI	INITIAL MANDU SETTING	11	
1 1 2 2	FIRST-TIME-ON SAMPLE NUMBER	- 3	
Z I	BLING DORALION IN SAMPLES AZIMUTH ANGLES OF INCIDENCE (DEG)	00000 01 1	

ZX Z Z Z Z	AMPLITUDE OF NJISE SOUNCE INITIAL RANDU SETTING FIRST-TIME-ON SAMPLE NUMBER BLINK DURATION IN SAMPLES AZIMUTH ANGLES OF INCIDENCE (DEG)		100000
CHANNEL 4 :- AN	AMPLITUDE OF NOISE SOURCE INITIAL RANDU SETTING FIRST-TIME-ON SAMPLE NUMBER BLINK DURATION IN SAMPLES AZIMUTH ANGLES OF INCIDENCE (OEG)	: 1111 : 1111 : 10000	11111
PORT PARAMETERS DO I AN NS I NU NPORTS I NU	TERS ANTENNA-ELEMENT SEPARATION FACTOR NUMBER OF SIGNAL SAMPLES NUMBER OF PORTS		1.00000 128 5
PORTO : NEL LOCI BWFCTR = BWOFF	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTUR BANDWIDTH UFFSET FACTUR		255 1 1.00000
PORTI : NEL - LOCI - BWFCTR - BWOFF -	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH IOLERANCE FACTOR BANDWIDTH OFFSET FACTOR		1.00000
PORTE : NEL LOCI BMFCTR - BWOFF -	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTOR BANDWIDTH OFFSET FACTOR		1.00000 1.00000
PORT3 1 NEL LUC1 BWFCTR	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLEKANCE FACTOR		1 127 1.00000

00000	1 255 1.00000
	~~~
BEGT - BANDEIOTH OFFSET FACTOR	PORTA : NEL - NUMBER OF ANTENNA ELEMENTS LOCI - LOCATION OF THE FIRST ELEMENT BWFCTR - BANDWIDTH TOLERANCE FACTOR BWOFF - BANDWIDTH OFFSET FACTOR
) .	
	PORT4 : NEL LOC1 BWFCTR BWOFF

		TAYLUR WEIGH	WEIGHTING FOR	MAIN ANTENNA	A ARRAY		
.5000¢	.50034	\$6005	.50186	.50307	.50458	.50640	.50851
.51093	.51364	.51664	.51994	. 52353	.52741	.53157	.53602
.54076	.54577	.55105	.55661	.56244	.56853	.57489	.58150
.58837	.59549	.60285	94019*	.61830	.62637	.63467	.64319
.65193	.66088	+00/9*	46619.	♦6889	89869	,70860	.71870
12897	.73941	.75000	. 76074	.77163	. 78266	. 19382	.80511
.81651	.82802	.83964	.85136	.86317	.87506	.88702	90668.
.91115	.92330	.93550	.94773	00096	.97229	09486.	.99692
1.00924	1,02155	1.03385	1.04613	1,05838	1.07060	1.08278	1.09490
1,10697	1,11897	1.13090	1.14275	1.15451	1.16618	1.17774	1.18920
1.20055	1,21177	1.22287	1.23383	1.24465	1.25531	1.26583	1.27618
1.28637	1,29638	1.30621	1.31585	1,32531	1,33456	1.34362	1.35246
1.36109	1,36950	1.37769	1.38565	1.39337	1.40086	1.40810	1.41509
1,42183	1,42832	1.43454	1.44051	1.44620	1.45162	1.45677	1.46164
1.46624	1.47054	1.47457	1.47830	1.48175	1.48490	1.48776	1.49032
1.49258	1.49454	1.49621	1.49757	1.49863	1.49939	1.49985	1.50000
1.49985	1.49939	1.49863	1.49757	1.49621	1.49454	1.49258	1.49032
1.48776	1.48490	1.48175	1.47830	1.47457	1.47054	1.46624	1.46164
1.45677	1.45162	1.44620	1.44051	1.43454	1.42832	1.42183	1.41509
1.40810	1.40086	1.39337	1.38565	1.37769	1,36950	1.36109	1.35246
1.34362	1,33456	1.32531	1.31585	1,30621	1.29638	1.28637	1.27618
1.26583	1,25531	1.24465	1.23383	1.22487	1,21177	1.20055	1.18920
1.17774	1.16618	1,15451	1.14275	1.13090	1.11897	1.10697	1.09490
1.08278	1.07060	1.05838	1.04613	1.03385	1,02155	1.00924	.99692
09486	.97229	00096*	.94773	.93550	.92330	.91115	90668.
.88702	.87506	.86317	.85136	.83964	.82802	.81651	.80511
. 79382	. 78266	.77163	.76074	.75000	. 73941	, 7289 <i>†</i>	.71870
.70860	9969.	*6889*	.67939	•6700	.66088	65169	61649.
.63467	.62637	.61830	.61040	•60285	.59549	.58837	.58150
.57489	.56853	.56244	.55661	.55105	.54577	.54076	.53602
.53157	.52741	.52353	51994	.51664	.51364	.51093	.50851
.50640	.50458	.50307	.50186	\$6005	\$2003	* 0000 \$	

		RECE IVER	HASEBAND	HASEBAND CHARACTERISTICS	ST1C5		
			AMPLITUDE	VOE			
.21887	.24898	.28493	.32799	+9516.	.44131	.51399	.59734
.68840	.78038	.86323	.92737	.96864	98686	00866	88666
1.00000	88666	.99810	09066.	.97150	.93510	9681A.	.80611
,72383	.64035	.56184	.49158	.43054	.37834	33405	*566*
			PHASE	1 ند			
2.42933	2,37392	2,30990	2,23532	2.14777	2.04434	1.92177	1.77689
1.60773	1.41510	1.20424	.98457	.76677	.55867	.36306	.17828
00000	17716	35838	54754	74596	95120	-1,15697	-1,35471
-1,53694	-1.69888	-1,83942	-1,95978	-2.06240	-2.14996	-2,22503	-2.28976
			IMPULSE RESPONSE	ESPONSE			
.00567	.00075	00618	00072	.00000	69000	00725	00066
.00783	.00063	00847	- 000059	.00918	•00026	-,00999	00052
.01096	7+000.	01214	00042	.01365	.00035	01569	00027
.01865	• 00015	02342	.0000	•03245	00031	05579	84000.
.23241	01276	*2199*	.01673	.18167	.00393	-,00713	61600*-
03027	00002	00291	00064	00038	.00187	.00117	00113
*6000	.00103	00167	00106	.00230	.0000	00299	00092
0.00	: 0000		1000	*****			

CHANNEL BASEBAND CHARACTERISTICS O2516 .03111 .03819 .04721 .05741 .07175 .13021 .15612 .17942 .20275 .21973 .23489 .26303 .27156 .27949 .28597 .28855 .29593 .23889 .21616 .19387 .17358 .15566 .13909 .23889 .21616 .19387 .27640 .2.75840 .2.8593 .23889 .21616 .19387 .2.75840 .2.8593 .20388 .2.6738 .2.67416 .2.75840 .2.85401 .27740 1.10573 .92522 .73514 .20368 .06104 .05964 .16655 .25084 .31677 .00107 .00086 .00104 .00125 .00118 .00126 .00104 .00525 .00013 .006217 .00353 .00109 .00984 .00134 .00504 .00131 .00106 .00108 .00129 .00091 .00131 .00109 .00983 .00270 .00081 .00131 .00109 .00983 .00270 .00131 .00131 .00134 .00128 .00129 .00131 .00131			INOG	0	CHANNEL 1			
CHANNEL BASEBAND CHARACTERISTICS O3111 .03819 .04721 .05741 .07175 .15612 .17942 .28597 .21973 .23489 .27158 .27949 .28597 .28855 .28593 .21616 .19387 .17358 .15566 .13909 .27615 .27740 .17358 .15566 .13909 .269825 .249650 .2.29800 .2.10861 .43937 1.27740 1.10573 .92522 .73514 .06104 .05964 .16455 .25984 .31677 .00086 .00104 .10455 .00188 .00126 .00169 .00108 .00134 .00131 .00525 .00013 .00204 .00134 .00526 .00184 .00204 .00363 .00883 .00270 .00087 .00131 .00983 .00270 .00087 .00168 .00184 .00151 .00094								
AMPLITUDE .03111 .03819 .04721 .05741 .07175 .15612 .17942 .20275 .21973 .23489 .27156 .27949 .28597 .28855 .28593 .21616 .19387 .17358 .15566 .13909 .2 89006 2.69825 2.49650 2.29800 2.10861 1.43937 1.27740 1.10573 .92522 .73514 .06104 .00104164552508431677 .00086 .001041012500118 .00126 .07904001080018400092 .005250001300681 .0020400131 .0052500158 .004440016600131 .00618 .00158 .000440016600013	•	1	CHANNEL	BASEBAND	CHARACTERI	ST1CS		
.03111 .03819 .04721 .05741 .07175 .23489 .27158 .27949 .28597 .28855 .23489 .27158 .27949 .28597 .28855 .288593 .21616 .19387 .17358 .15566 .13909 .21616 .19387 .17358 .15566 .13909 .21616 .258440 -2.62338 -2.67416 -2.75840 -2.83401 .2.69825 .2.49650 .2.29800 .2.10861 .1.43937 .2.67440 .2.67416 -2.75840 -2.83401 .2.69826 .73514 .26104 -2.16455 -2.25084 -31677 .25084 .31677 .00276 .00128 .00126 .00126 .00121 .00126 .00128 .00126 .00121 .00				AMPLIT	UDE			
15612 .17942 .20275 .21973 .23489 .21616 .19387 .17358 .15566 .13909 .21616 .19387 .17358 .15566 .13909 .21616 .262338 .2.67416 .2.75840 .2.83401 .2.89006 .2.69825 .2.49650 .2.29800 .2.10861 .1.10573 .92522 .73514 .06104 .06104 .06104 .00108 .00126 .00082 .00118 .00126 .00169 .00169 .00184 .00181 .00052 .00956 .00018 .00169 .00013 .00270 .00270 .00087 .00204 .00151 .00069 .00013 .00270 .000270 .00037 .00166 .00013 .00074 .00018 .00012 .00013 .00018 .000	41200	11110	03819	.04721	.05741	.07175	. 08866	.10756
27156 .27949 .28597 .28855 .28593 .215166 .19909 .1556 .1556 .13909 .1556 .1556 .13909 .1556 .1556 .13909 .1556 .1556 .13909 .25840 .2.62338 .2.67416 .2.75840 .2.10861 .75840 .2.10861 .75840 .2.69825 .2.69826 .73514 .06104 .05964 .16455 .255084 .31677 .05964 .16455 .255084 .31677 .00086 .00104 .00125 .00118 .00126 .00169 .001084 .00118 .00126 .00363 .00576 .00083 .00270 .00087 .00169 .00164 .00166 .00013 .00074 .00151 .00074	10001	15612	17942	20275	.21973	.23489	.24453	.25425
21616 19387 17358 15566 13909 21616 262338 -2.67416 -2.75840 -2.83401 2.89006 2.69825 2.49650 2.29800 2.10861 1.43937 1.27740 1.10573 92522 7.3514 0610405964164552508431677 001086 .001040012500118 .00126 00169 .000040018400181 .00363 005250001300681 .00052 .00363 007904019640051 .0053100683 .00270 .000870016600013	12061.	2715	27949	28597	.28855	.28593	.27593	.25933
PHASE 2.58440 -2.62338 -2.67416 -2.75840 -2.83401 2.89006 2.69825 2.49650 2.29800 2.10861 1.43937 1.27740 1.10573 92522 73514 0610405964164552508431677 00086 .001040012500118 .00126 00169 .000940018400082 .00217 005250001300681 .00052 .00363 0079040196400481 .00052 .00353 00790401964001660013100074 .00158 .000770016600013	.23889	.21616	19387	17358	.15566	60661.	,12534	,11333
-2.58440 -2.62338 -2.67416 -2.75840 -2.83401 -2.899006 2.69825 2.49650 2.29800 2.10861 1.43937 1.27740 1.10573 92522 73514 0.610405964164552508431677 1.27740 1.10573 92522 73514 0.10686 0.00104001252508431677 1.27740 1.0012500126 0.00126 0.00126 0.00126 0.00131 0.00525 0.0031400131 0.00526 0.00131 0.00526 0.00131 0.00681 0.0050400131 0.00126 0.00013 0.00121 0.00121 0.00014 0.00121 0.00014				PHAS				
-2.5840 -2.62338 -2.67416 -2.75840 -2.83401 -2.69906 2.10861 1.43937 1.27740 1.10573 .92522 .73514 .0610405964164552508431677 .31677 .00108 .001040012500118 .00126 .00169 .001080013400131 .00363 .0052500131 .00363 .0052600131 .00681 .0015600131 .0036400131 .0015600131 .00074 .00121 .00074 .00121 .00074					•			1
2.89006 2.69825 2.49650 2.29800 2.10861 1.43937 1.27740 1.10573 .92522 .73514 .0610405964164552508431677 .001086001040012500118 .00126 .002760018400181 .00363 .005250001300681 .00052 .00956 .079040196400810052 .0052600131006810020400131 .00740015800440016600013	-2.54147	-2.58440	-2.62338	-2.67416	-2.75840	-2.83401	-2.93445	-3.07337
1,43937 1.27740 1.10573 .92522 .73514 .0610405964164552508431677 .00106001040012500118 .00126 .0057600013006810005200315 .0052500013006810005200956 .0790401964006810050400131 .006830027000870020400131 .0007400158000440016600013	3.067A4	2.89006	2.69825	2.49650	2.29800	2,10861	1.92829	1.76085
06104059641645525084	1.60033	1.43937	1.27/40	1.10573	.92522	,73514	54932	.36945
.00086 .00104 .00125 RESPONSE .00169 .00094 .00184 .00018 .00276 .00068 .00184 .00082 .00525 -00013 .00681 .00052 .07904 -01964 .16878 .02107 .07904 .00270 .00087 .00204	20368	.06104	05964	-,16455	25084	-,31677	-,37486	45064
IMPULSE RESPUNSE 00086 .001040012500118 00169 .000940018400081 005250001300681 .00052 0790401964 .1687802107 00883 .00270 .0008700204 00074 .00158 .0004400166				1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1				
. 00086 . 00104 - 001125 - 00118 . 00169 . 00094 - 00184 - 00082 . 00526 . 00068 - 00314 - 00051 . 00525 - 00013 - 00681 . 00052 . 07904 - 01964 . 16878 - 02107 . 00983 . 00270 . 00087 - 00204 . 00074 . 00158 . 00044 - 00166	•			IMPULSE R	ESPONSE			
.00169 .000940018400082 .002760001300681 .00052 .00790401964 .1687802107 .00983 .00270 .0008700204 .00074 .00158 .0004400166 -	70100	4000	40100	1,00125	00118	.00126	.00101	00151
7 .00276 .0006800314 .00051 6 .005250001300681 .00052 8 .0790401964 .1687802107 900883 .00270 .0008700204 600074 .00158 .0004400166 -			10000	44.00	- 000082	.00217	0000	00244
\$.005250001300681 .00052 \$.0790401964 .1687802107 900883 .00270 .0008700204 600074 .00158 .0004400166 -	20100-	**************************************	******	-00314	0000	00363	44000	00426
8 .0790401964 .1687802107 900883 .00270 .0008700204 600074 .00158 .0004400166 -	10000 ·	0/200		4400	25000	95600	00163	01688
-,00883 .00270 .0008700204 -,00074 .00158 .0004400166 -,00018 .001210003700121	*****	0.000	44010	16878	- 02107	.03532	.00277	00075
00074 .00158 .0004400166 -	90100		06000	74000	40200	00131	.00174	.00136
12100 12100. HODD.	**************************************	7.000	24.00	44000	99100	E1000-	00149	.0000
	00100-	* 2000	00100	F 6 0 0 0	10100	₹2000°	00100	57000-
	00134	91000	10100	10000	4 3 4 0 0 0 0			

		POR	9	CHANNEL 1			
		•					
		RECE I VED	BASEBAND	CHANNEL S	SIGNAL		
.00187	.00323	01627	03101	00430	12111	.00505	-,13317
.00402	~	0052	1267	0	13	9800	11011
.01396	07821	.01617	.03235	02411	.01303	.01298	04663
.01499	.05881	00386	.10206	02370	.05140	00163	05167
.00452	02603	86400.	-,03625	.01859	.07055	60	.05202
96900	0263	00149	.01150	.00726	.00837	00539	.05801
02007	04303	.01769	-,05763	20	 00879	*01474	.00045
.00338	960	01962	.04148	60110 •	.014B0	16500.	.09187
02249	3	00349	03437	.01161	004Bl	00163	•02496
.00267	6	.00131	.05130	.00327	.07865	 00878	.07727
.00012	962	0136	.04679	00685	03073	96800.	02676
00078	00556	00355	01778	.00576	-, 02992	+0+10.	.03470
00900	11	01020	.04013	00086	.00360	.00653	.02997
01482	*6010*	.01523	01241	60000-	734	02265	00618
• 00655	06727	.02300	.01137	00281	9	02559	.02531
.00242	05410	.01166	01629	00698	980	00230	04610
.01451	00824	• 00698	•05159	+1100.	126	03047	.03335
.01399	03259	00149	.03038	.00142	*9000	1.000	.06811
00549	.09189	01406	.05179	.00605	165	01509	. 03259
01512	11005	.01699	09279	00667	0	.02499	05323
01211	00779	.01906	02405	++600.	.10518	01271	.09842
00034	.08088	.00284	16660	00282	13020	01214	E6660°
80800°-	an.	00317	.02078	0	.02751	01758	00557
00544	-,10526	.02870	05102	00046	.05391	*6100	.04251
.00043	æ	+6/10	06620*	•00654	9.900	.01286	BE640.
00426	.10868	01377	.04661	.00922	.05311	01678	509E0.
.00788	.00391	01264	.01274	.01129	02814	.00613	• 06966
01626	.02858	01009	66870*-	.00325	986	Ž	10+10.
02598	.04037	.00100	06509	.01224	00975	ũ	* 6000.
.01025	.01370	.00242	.07343	01282	•	025	.00510
.00748		.00363	3	.00382	•08629	6	.10863
01287	.03734	.00560	.03335	01634	.00887	.01133	03585

			POHT	0 1			
		RECEIVED	U BASEBAND	PORT SIGNAL	IAL		
.00187	.00323	01627	03101	00430	12111	.00505	13317
.00402	13817	.00524	12671	•00335	13047	.00868	11011
.01396	07821	.01617	.03235	02411	.01303	.01298	04663
.01499	.05881	00386	.10206	02370	.05140	00163	05167
.00452	02603	.00498	03625	•01859	.07055	02890	.05202
96900.	02636	00149	.01150	.00726	.00837	00539	.05801
02007	04303	.01769	05763	00277	00879	.01474	.00045
.00338	.09579	01962	.04148	.01109	.01460	16500	.09187
-,02249	.06113	00349	03437	.01161	00481	00163	•05460
.00267	.03042	.00131	.05130	.00327	.07865	00878	.07727
.00012	.06209	01363	.04679	00085	03073	.00895	02676
00078	-,00556	00355	01778	.00576	2	+0+10.	.03470
00600	.07720	01020	.04013	00086	.00360	.00653	.02997
01482	.01094	.01523	01241	60000	.07345	02265	00618
.00655	06727	.02300	.01137	00281	.11030	02559	.02531
.00242	 05410	.01166	01629	00698	.00341	00230	04610
.01451	-, 00824	86900.	.05159	.00114	.11260	03047	.03335
.01399	03259	00149	9E0E0	.00142	*9000	1,000.	.06811
00549	.09189	01406	.05179	• 00000	.01652	01509	.03259
01512	11005	.01699	09279	00067	-,10155	.02499	05323
01211	00779	•01906	02405	*****	.10518	01271	24860.
00034	.08088	•00584	16660.	~•00582	.13040	01214	6660.
90800	.05787	00317	.02078	.00185	.02751	-,01758	00557
00544	-,10526	.02870	05102	00046	.05391	.00134	.04251
E\$000°	.08879	01794	06620*	•00054	9/900-	.01286	•04938
00426	.10868	01377	.04661	.00922	.05311	01678	.03809
.00788	.00391	01264	.01274	.01129	02814	.00613	99690.
01626	.02858	01009	02899	.00325	09887	.02942	.01401
02598	.04037	.00109	06509	.01224	-,00975	00453	*6000
.01025	.01370	.00242	.07343	01282	.04849	-,00252	.00510
.00748	.01670	.00363	.06073	.00382	• 08629	00903	.10863
01287	.03734	.00560	•03335	01634	.00887	.01133	03585

24898 .28493 .78038 .99810 .99988 .99810 .64035 .56184 .56184 .56184 .17392 2.30990 2.17716 -35838 .1.69888 -1.83942 -1.	AMPLITUDE 32799 92737 99060 49158 PHASE 2.23532 2.23532 2.23532 2.23532 2.23532 2.23532 2.23532 2.23532 2.23532	BASEBAND CHARACTERISTICS AMPLITUDE .32799 .92737 .96864 .92737 .96864 .99060 .97150 .9 .49158 .43054 .3 .2.23532 .2.14777 .2.0 .96457 .54754 .1.95978 .2.06240 .2.1	. 44131 .98988 .93510 .37834 2.04434 .55867 -95120 -2.14996	.51399 .99800 .87898 .33402 .1.92177 .36306 -1.15697 -2.22503	.59734 .99988 .80611 .29644 .17689 .17828 -1.35477
		SPONSE			
•	2000	0.400	94000	00725	-,00066
•	31000	2000	A 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0		
- 14800 69000	• 00005	.00918	•00056	66600	00052
•	.00042	01365	.00035	-,01569	00027
		34060	(5000	05570	40000
00015 02342	70000	.03245	1.000	6/CCO	
	.01673	18167	.00393	00713	61600
•	*9000	00038	.00187	.00117	00113
00100 - 00100	90100	05.200	75000	66200	00092
ĭ					
	3000	77744	2000	4 1 U C C	

		P081		CHANNEL 1			

		CHANNEL	BASEBAND	CHARACTERISTICS	51105		\$ 9 9
	; ; ; ; ;	# 	AMPL 11UDE	UDE			
221887	24898	28492	.32799	.37964	.44131	.51399	.59734
68840	78038	.86322	.92737	*9896*	98686	00866.	88666
1,0000	88666	01866	09066	.97150	.93510	86818.	11908.
,72383	.64035	.56184	4915B	.43054	,37834	33402	.29644
	1		PHASE	E			
						•	
-1.63464	-1.68991	-1.75379	-1,82823	-1.91564	-2.01893	-2.14137	-2.28610
-2.45512	-2.64761	-2.85834	-3.07787	2,98766	2,17969	2.58422	2,39958
2.22144	2.04442	1.86334	1.67432	1.47604	1.27093	1.06531	.86765
.68561	.52380	.38341	.26318	.16071	.07328	00158	-,06624
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1							
T			IMPULSE R	RESPONSE			
20400	20400	.00433	00447	00460	.00491	.00491	00536
40500	00584	00260	00637	00900	96900	.00646	00764
10005	64800	69200	14600-	00855	.01065	\$7400.	01233
01143	.01476	.01419	01866	01944	.02603	.03306	04504
13091	19303	41410	.51634	-,11293	14190	.01162	00010
01837	02410	.00224	00189	00124	00145	.00017	.00104
00137	.00011	.00184	00067	00215	.00123	.00253	00181
00286	.00230	.00317	00276	00346	.00320	*4400	00363

		P 0		CHANNEL			
		RECEIVED) BASEBAND	CHANNEL S	SIGNAL		
00340	.00652	.04613	07209	.26888	34846	.31180	40276
.31767	41781	.29436		.29872	39376	.26236	34145
.19522	25197	04857	.06680	06972	.06686	.12620	14657
10984	.15034	23979	.30403	15213	.18482	.11582	14052
96690	08479	.08520	11207	12997	.17915	16552	.18877
.07218	07781	02659	.03357	00973	.01678	-,13809	.17378
.06457	09603	.16158	18976	.01451	02822	.01887	01642
21095	.27281	12630	.15076	01459	.03616	19797	.26070
17397	.20951	•07364	08837	.03116	02900	06111	.07312
06552	.08707	11482	.15059	17280	.22880	-, 18895	.24123
-,13898	.18697	12492	.15615	.05941	07618	.07649	08981
.01073	01856	*****	04874	.07581	09391	05686	.08182
-,18580	.23262	10630	.13467	00844	.01658	05584	*9610*
04875	.05071	.05149	05114	16490	.21080	02295	.01385
.16476	20088	.00931	.00171	25598	.32161	90860	.11167
.13042	15579	.05650	06504	01938	.01444	.09953	13040
.04242	+1+00-	10982	.14154	25318	.32856	12322	14141
95860.	-,10502	++0/0	.06748	01146	.01458	-,13845	.18694
-,21795	.27815	13799	.17444	02661	.04711	09293	11096
.22448	29827	.44151	29789	.21553	29541	15937	19265
34400	01416	96180	09115	22331	.29189	24615	.30866
-, 18169	.24466	22148	68462.	29891	.38966	24474	.31532
14103	.18655	05076	.07009	 05808	.07965	01371	.00535
.23040	29841	.16103	18881	12567	15019	09768	.12613
-, 19760	.26021	 09578	76411.	.02778	02303	09256	.12862
25307	, 32236	12913	.16164	10205	.14851	11267	.13418
.00456	.00631	04750	.05164	.07945	-,09208	14672	.19189
09239	.10657	.05449	~	.22810	29076	.01560	00230
-,13516	.14515	•14936	655	01440.	04715	01199	.00633
01621	.02869	16242	. < 1076	13045	10101	01416	. 02333
02548	.04122	13247	.17274	19119	. 25135	25898	.33251
10444	.13347	06328	.09438	04536	.04705	.09816	11456

			PCRI	1			
		RECEIVED	BASEBA	PORT SIGNAL	4AL		
00340	.00652	.04613	07209	.26888	34846	.31180	40276
.31767			38674	.29872	393 <i>ì</i>	. 26236	-,34145
.19522	25197	04857	.06680	06972	.06686	.12620	14657
10984	.15034	-,23979	E0+05.	15213	.18482	.11582	14052
.06938	08479	.08520	11207	12997	.17915	-,16552	.18877
.07218	07781	02659	.03357	00973	.01678	99	.17378
.06457	-,09603	.16158	18976	.01451	02822	.01887	01622
21095	.27241	-,12630	.15076	01459	.03616	19797	.26070
17397	.20951	•07364	08837	.03116	02900	06111	.07312
06552	.08707	-,11482	.15059	17280	.22880	18895	.24123
13898	.18697	12 4 9 2	.15615	.05941	07618	.07649	08981
.01073	01856	44460.	04874	.07581	09391	05686	.08182
-,18580	.23262	10630	.13467	++800	.01658	-,05584	.07964
04875	.05071	.05149	05114	16490	.21080	-,02295	.01385
.16476	2008 u	.00931	.00171	25598	.32161	90860*-	.11167
.13042	15579	.05950	06504	01938	***10.	.09953	13040
. 04242	+1440	10982	.14154	25318	,32856	-, 12322	.14141
.09856	10502	07044	.06748	01146	.01458	13845	.18694
-,21795	.27815	-,13799	***27.	02661	.04711	09293	.11096
.22448	29827	151470	29789	.21553	29541	15931	-, 19265
04400	01416	96180.	09115	22331	.29189	24615	30866
18169	.24466	22148	68462.	29891	.38966	24474	.31532
14103	.18655	05076	.07009	05808	.07965	01371	.00535
.23040	29841	.16103	18881	12567	.15019	09768	.12613
19760	.26021	09578	.11499	.02778	02303	09256	.12862
25307	.32236	12913	.16164	-10205	.14851	11267	.13418
•00456	.00631	04750	•05164	.07945	09208	14672	.19189
09239	.10657	.05449	07049	.22810	29076	-	00230
-,13516	.14515	.14936	30	.04410	04715	Š	.00633
01621	.02869	16242	.21076	13045	•	ŭ	.02333
0254B	.04122	13247	.17274	19119	.25135	25898	,33251
10444	13347	06328	8E+60.	04536	.04705	.09816	-,11456

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_			PORT	~ ;			
		RECEIVER	BASEBAND	HASEBAND CHARACTERISTICS	\$71¢\$		
			AMPL I TUDE	UDE			
.21887	.24898	.28493	.32799	.37964	16144.	.51399	.59734
.68840	.78038	.86323	.92737	.96864	.98988	.99800	99666
1.00000	98666	.99810	09066	.97150	. 93510	96848	.60611
. 12383	CE040.	+919C*	96144.	*5054.	47075.	20455.	*****
			PHASE	W •			
2,42933	2,37392	2.30990	2,23532	2.14777	Ň	1.92177	1.17689
1.60773	1.41510	1.20424	.98457	.76677	.55867	.36306	.17828
00000	17716	35838	54754	74596	Ĭ	-1.15697	-1.35477
-1,53694	-1.69888	-1.83942	-1.95978	-2.06240	-2.14996	-2,22503	-2.28976
			IMPULSE R	RESPONSE			
.00567	.00075	00618	00072	.00670	69000.	00725	00066
.00783	.00063	00847	00059	.00918	•00026	00999	00052
.01096	.0000	01214	00042	.01365	.00035	01569	00027
.01865	.00015	02342	*0000	.03245	00031	05579	86000
.23241	01276	.66174	.01673	.18167	.00393	00713	00919
03027	00002	00291	0000	00038	.00187	. 00117	00113
* 6000.	.00103	00167	00106	• 00530	.00097	00299	00092
.00358	.00088	00413	00085	•00466	.00081	00517	00078

		1404	2 2	CHANNEL 1			
		CHANNEL	BASEBAND	CHARACTER ISTICS	51105		
			AMPLITUD	UDE			
.21887	84842°	.28493	.32799	.37964	16144.	.51399	.59734
0489	.78038	.66323	.92731	.96864	88686	00866	RR666.
3.00000	88666	01955.	09065.	.97150	.93510	96878.	.80611
.72383	.64035	*8195*	9516+*	*4305+	.37834	.33402	.29644
			PHASE				
2.51224	2,46391	2.40097	24088	2.25401	2,16266	2,04716	1.60937
1.74729	1.56174	1.35795	1.14536	.93465	.73364	54509	36741
.19621	.02607	14802	33016	52144	71967	91830	-1.10907
-1.28412	-1.43904	-1.57245	-1.68578	-1.78127	-1.86171	-1.92974	-1.98735
			IMPULSE RESPONSE	ESPONSE			
.00477	.00174	00533	00182	06500	.00192	00650	00202
•00714	.00212	00784	00223	.00861	.00236	00950	00251
.01054	.00268	01182	60290	.01345	.00318	-,01565	00356
.01882	11+00.	02391	00500	.03348	27900.	05810	01119
.25414	.03792	26049.	14524	16034	.03464	00476	16600
03118	00624	00045	00057	00222	.00133	.00272	00054
00053	99000.	40030	60100	+0100.	.00117	00180	00128
•00246	.00138	00306	00147	•00365	.00156	·•• 0042j	00165

	† • • • • • •	PORI) 7 12	CHANNEL 1			
		VE	D BASEBAND		SIGNAL		
66800.	.00063	09615	01192	43913	0/060	49835	-10294
-,51525	10220	4751	9942	•	98560	6/14	08488
30482	06371	.09618	F0810.	.07588	.03002	_	0.04800
.19675	.03620	.37983	. 08225	.21837	.05265	1832	04432
10307	02359	13722	04791	.23507	.04248	, 22535	.06217
10077	03111	.04247	\$6600.	.02342	.00172	.21722	.04872
13138	02012	23229	05988	03205	00032	01419	00867
.34549	.07221	.17/84	50440.	****0.	00188	.32921	.06575
.25167	.06165	11818	-,02933	03194	01320	16260.	*0250*
.10940	.02100	.18790	.03750	.28597	.05586	.29572	.06303
.22476	.04287	.18767	.04549	10222	02200	10927	02803
02116	00133	06758	01015	11572	02682	10974	.01777
.2900B	.06488	.16126	.03488	.01646	00035	.10176	•016/5
.05758	.01956	-0190-	02262	.26672	•02100	*1900 *	.01058
25253	06008	.01358	00559	.40589	94060.	12582	.03487
19981	04962	07554	02024	.01852	.01071	-,16516	03367
04851	01646	.18190	.03777	.41209	·0840·	.16069	.04402
-,13248	04181	.11149	• 05616	.01/87	.00312	.23017	67440.
.34492	.07356	.20869	.04556	.05628	•00336	.13379	.03440
-,38335	07544	36396	UB339	36701	06582	42693	05513
01675	51600°	10797	03247	.37257	.07603	.37919	.08390
.30038	.05595	.36587	-0103	.48332	.09821	.38433	.07997
.22434	.04380	. 08212	.01405	.09912	.01792	00037	.00789
37833	07857	22256	05792	.19472	.04852	.15704	.03180
.32461	.06480	13291	.03258	03057	14410	.16620	.02889
.40287	.08681	. 19179	.04226	. 1854Ú	.02834	15987	.04028
.00739	-,00635	.06045	01610.	11351	03095	.24582	.05051
.12569	.03347	09504	01934	36499	07885	.01338	00/54
17626	.05514	23671	05469	05264	01632	.00838	.00729
•03956	·0031<	.26572	•	•	.04400	.02416	99100.
.05307	.00584	.21815	.04435	.31428	.06218	06014.	.086/0
.15587	.03505	.11068	.01663	.05176	.01807	14205	03/74

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		MECEIVED	EU BASEBAND	PURT SIGNAL	VAL		
66800.	.00063	09615	01192	43913	0.060	49835	10294
5152>	10220	47517	09424	48557	09588	41791	08488
-,30482	06371	. 09618	.01803	.07588	.03002	-, 18283	04890
. 19675	.03620	.3/983	.06225	. <1837	.05265	18323	04432
10307	02359	-,13722	02791	.23507	.04248	, 22535	.06217
10077	03111	14240.	96600.	.02342	.00172	.21722	.04872
-,13136	02012	23229	98650.	03205	00032	01419	00867
.34549	.07221	.17784	F0440.	****0.	00188	12625.	.06575
.25167	.06165	11816	02933	03194	01320	.09297	*0229*
.10940	.02100	18790	03750.	16585.	.05586	.29572	.06303
.22976	.04287	.16767	.04249	10222	02200	10927	02803
-,02116	00133	06158	01015	11572	02682	10974	.01777
.29008	98490.	16126	.03488	.01046	00035	.10176	.01675
.05758	.01956	+0190	04282	.26672	.05764	+1900.	.01058
-,25253	06008	.01358	00559	40589	94060.	, 12582	.03487
19981	04962	07554	02024	.01852	.01071	-,16516	03367
04851	01646	.18190	.03777	.41209	+6+80	. 16069	.04402
-,13248	04181	.11149	• 02010	.01787	.00312	.23817	.04473
.34492	.07356	69807.	.04556	.05628	.00336	13379	.03440
-,38335	07544	36396	08339	36701	-,06582	22693	05513
01675	61600.	10797	03247	,37257	.07603	.37919	.08390
.3003a	.05595	.36587	.07032	.48332	.09821	.38433	.07997
.22434	04380	.08412	.01405	.09912	-01792	00037	•00789
-,37833	U7857	-,22256	05792	.19472	.04852	.15704	.03180
.32461	08490.	13291	.03258	03057	19410	.16620	68820.
.40287	.08681	.19179	.04226	.18540	.02834	18651.	•04058
.00739	-,00635	.06045	01610.	11351	03095	.24582	.05051
,12569	.03347	+0560	01934	66498	07885	.01338	00754
17626	.05514	23071	05469	05264	01632	.00838	•00129
. 95660.	.00312	.26572	.05467	.19475	09440.	.02416	.00108
.05307	•0058	.21815	.04435	.31428	.06218	.41030	.08670
15587	.03265	.11668	.01663	.05176	.01607	14205	03774

			PCKT				
		RECEIVER		BASEBAND CHARACTERISTICS	\$71C\$		
			AMPL I TUDE	UDE			
.21887	.24898	.28493	.32799	.37964	16144.	.51399	\$5134
.68840	.78038	.86323	.92737	.96864	98686	00866	98666
1.00000	99666	.99810	09066	.97150	.93510	86878.	.80611
.72383	.64035	.56184	.49158	•4305+	.37834	.33402	.29644
			PHASE				
2,42933	2,37392	2.30990	2.23532	2.14777		1.92177	1.77689
1.60773	1.41510	1,20424	.98457	.76677		36306	.17828
00000	17716	-,35838	54754	74596	95120	-1.15697	-1.35477
-1.53694	-1.69888	-1.83942	-1.95978	-2.06240	-2.14996	-2.22503	-2.28976
			IMPULSE RESPONSE	ESPONSE			
.00567	.00075	00618	00072	.00670	.00069	00725	00066
.00783	.00063	00847	00059	.00918	•00026	66600*-	00052
.01096	~+000	01214	00042	.01365	.00035	01569	00027
.01865	\$1000.	02342	.00002	.03245	00031	05579	84000.
.23241	01276	.66174	.01673	.18167	.00393	00713	61600
03027	00002	00291	00064	00038	.00187	.00117	00113
16000	.00103	00167	00100	.00230	. 00097	00299	00092
.00358	.00088	00413	00085	•00400	.00081	00517	B1000

• • • • • • • • • • • • • • • • • • •	 	HOG	8	CHANNEL 1			
		CHANNEL		BASEBAND CHARACTERISTICS	STICS		1
			AMPL I TUD	UDE			
.21887	2489B	.28492	94726.	.37964	.44131	.51399	.59734
68840	78038	.86322	.94737	*9896	98686	00866	89666
1,0000	88656	.99810	09066	.97150	.93510	86878.	.80611
.72383	.64035	.56184	49158	*43054	.37834	33402	**967*
• • • • • • • • • • • • • • • • • • •			PHASE	E			
		1			4		10100
1,52681	1.48898	1.44253	1,38578	1,31581	1. £2996	000000000000000000000000000000000000000	76/66
.84633	.67128	.47799	.27590	.07592	11460		20704.
-,62029	78012	-,94351	-1.11510	-1.29594	-1.48361	-1.0715	10258.1-
-2.01636	-2.16073	-2.28369	-2,38647	-2.47126	-2.541,25	-2.59874	-2,64565
			IMPULSE R	RESPONSE			
04500	- 00163	71900-	40204	12400	00238	-,00525	.00281
48500	00324	- 00647	00370	.00719	-,00420	-,00800	.00482
40800	00550	01010	.00636	.01160	00743	01358	.00886
01644	-,01093	02103	.01423	.02963	02038	05160	.03605
23194	-17995	.53690	-,36096	.11385	08018	00941	00328
02757	95610	.00211	00177	00248	.00363	.00315	00341
00133	.00201	.00045	00144	.00023	.00091	06000*-	00039
.00155	00005	00209	.00048	.00263	00088	00315	.00126

• • • • • • • • • • • • • • • • • • •	Ĭ J J J J J J J J J J J J J J J J J J J	PORI		CHANNEL 1			•
		RECEIVED	D BASEBAND	• •	SIGNAL		D (1
69800.	00733	08925	.07255	-,37648	.26408	41547	.29281
42765	.30563	3921	.28077	4031	. 28839	14	.24305
24548	.17098	.09757	06953	.05395	02138	15428	.09402
.17818	-, 12931	,32124	22143	.16866	10955	1646	.10690
08319	.05714	11270	.07836	.21344	-· 15576	. i 7688	1063Í
-,08969	.04992	.03690	-,02344	.02294	020 <i>i</i> 2	.18403	12329
12597	.09546	19011	•11984	02305	.02431	00437	00482
.29838	40735	.13680	08862	.03695	-,03957	,28336	20078
. 19993	-, 12919	10983	•07026	02118	.0078S	19080	05228
.09331	•	.15874	11327	.24227	17399	.24306	16872
.18972	-,13899	.14948	10010	09542	.06522	08847	.05619
01535	.01460	05312	.04033	06560*-	.06338	10260	07746
.24465	16590	.12746	06809	.00868	01096	.08926	06712
.04124	02003	04791	09020*	.23015	15703	00937	.01662
21547	.14160	.02638	02820	.34860	23599	• 08866	05287
17544	.11295	05634	.03480	.01614	00271	-,14284	.09991
03242	.01561	.16034	11280	.35077	24591	.11535	60690**
11333	.06186	++260.	06331	.01454	01220	29102	15051
.28854	20017	.16481	11313	.04460	04173	.10723	06554
33830	.24021	29713	.20083	-,30828	.22782	***! T	.11336
01330	.02472	-,08393	.04542	,32556	22835	.31244	21398
.24766	-,18155	.30666	45194	+2+0+.	28606	31305	21983
.17895	12879	.06278	04790	.08362	06133	00937	.01645
-,32722	.22839	17100	.10650	.17365	11127	13191	09489
.27426	-,19436	.09865	06400	02787	.00963	.14793	11031
94108	23468	.14916	10310	•15/09	Ţ	12537	07962
.00581	01380	•04606	02373	09408	.05579	.21602	15033
.09653	05995	-,08921	.06366	-,31100	.21312	.03244	03338
.14220	07746	-,20676	.13679	03621	.02030	.00753	66000.
.03821	03325	.22802	-,15963	.15585	10477	142	01424
.04715	03921	.18767	13257	.26628	19089	.34073	23660
.11801	08351	.09756	07680	.03485	01560	11872	.07234

- 42765 - 24548 - 17818 - 08969	.00733	08925	.07255	37648	.26408	41547	.29281
- 24548 - 17818 - 08319 - 12547	.30563	39216	.28077	40310	.28839	34279	.24305
	.17098	.09757	06953	\$6530.	02138	15428	-09402
08319 08969 12597	.12931	.32124	22143	.16866	10955	16469	• i 0690
08969 12597	.05714	11270	.07836	.21344	•.15576	.17688	10631
12597	.04992	.03690	02344	•0220•	02072	.18403	12329
))))	.09546	19011	•11984	02305	.02431	00437	00482
- 2983a	.20735	.13680	08862	.03695	03957	.28336	20078
- 19993	.12919	10983	•01026	02118	.00785	.08067	05228
.09331	.06775	.15874	11327	.24227	-,17399	.24306	16872
.18972	.13899	94641	10010	09542	.06522	08847	.05619
01535	.01460	05312	.04033	06560*-	.06338	.10260	07746
- 24465	.16590	.12746	08809	99000	01096	92680.	06712
.04124	.02003	04791	09070*	.23015	15703	00937	.01662
21547	.14160	.02638	02820	.34860	23599	99880.	05287
17544	.11295	05634	.03480	.01614	00271	14284	16660.
03242	.01561	.16034	11280	.35077	24591	.11535	06909
11333	.06186	44260.	06331	.01454	-,01220	.20762	15051
- 28854	.20017	.16481	11313	.04460	04173	.10723	06554
33830	.24021	29713	.20083	30828	.22782	17449	.11336
01330	.02472	08393	.04542	.32556	22835	.31244	21398
- 54766 -	.18155	.30666	22194	+2+0+.	28606	.31305	21983
.17895	.12879	.06278	04790	.08362	06133	00937	.01645
32722	.22839	17100	.10650	.17365	11127	19161.	68460*-
- 27426	.19436	.09865	06406	02787	.00963	. 14793	11031
-3410B	.23468	.14916	10310	.15709	-, 12159	.12537	07962
- 00581	.01380	.04606	02373	 09408	.05579	-21602	15033
.09653	.05995	08921	• 06366	31100	.21312	.03244	03338
.14220 -	.07746	20676	.13679	03621	.02030	.00753	67000°
.03821	.03325	.22802	15963	.15585	10477	.01420	01424
- 04715	.03921	.18767	13257	.26628	-,19089	.34073	23660
-11801	.08351	.09756	0199/0*-	.03485	01560	11872	.07234

111-64

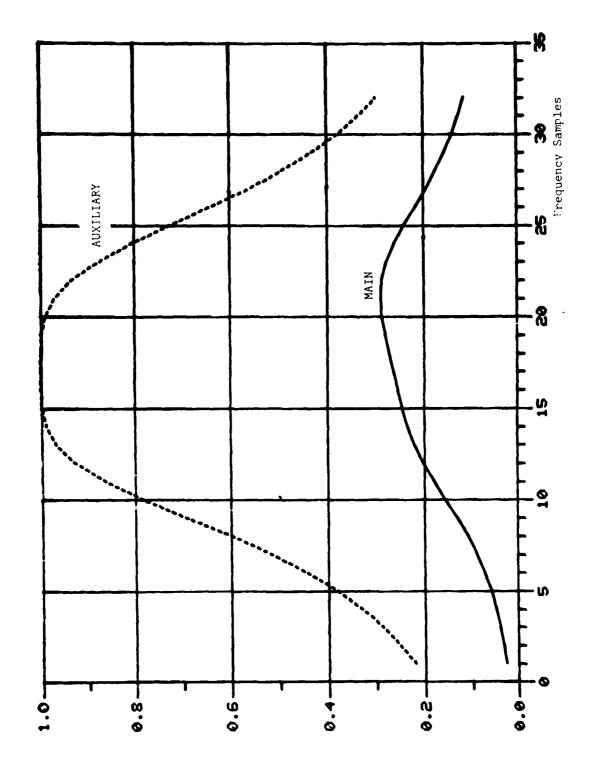
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		HECE IVER	BASEBAND	CHARACTERISTICS	STICS		
			AMPLITUDE	UDE	; ; ; ; ; ; ; ;		***************************************
.21887	.24898	.28493	32799	49626.	16144	905 14	707 7
.68840	.78038	.86323	.92737	96864	98988	00400	99999
1.00000	88666*	.99810	09066	.97150	93510	87898	404
.72383	.64035	.56184	.49158	43024	.37834	33402	2964
			PHASE	141			7 6 1 1 1 6
2.42933	2,37392	2.30990	2.23532	2.14777	2.04434	1.92177	1.77689
	1.41510		.98457	.76677	.55867	36306	17828
•	17716	35838	54754	74596	95120	-1.15697	-1.35477
-1.53694	-1.69888	-1.83942	3	-2.06240	-2.14996	-2.22503	-2.28976
			IMPULSE RESPONSE	SPONSE			
.00567	.00075	00618	00072	.00670	69000	00725	-,00066
.00783	• 00063	00847	00059	.00918	•00026	66600	25000-
.010%	.00047	01214	0004	.01365	\$6000.	-,01569	72000-
.01865	• 00015	02342	>0000.	.03245	00031	61550-	85000
.23241	01276	.66174	.01673	.18167	.00393	00713	01000-
03027	00002	00291	00064	00038	.00187	00117	- 0011
200	.00103	00167	00106	•00530	16000	00200	60000
A25 00 .	30000						

		POR	RI 4	CHANNEL 1			
		CHANNEL		BASEBAND CHARACTERISTICS	STICS	9 8 8 8 8 8	#
			AMPLITUDE	TUDE		• • • • • • • • • • • • • • • • • • • •	•
.21887	.24898	28492	32700	44075		00617	
.68840	. 78038	46322	75750	77770		887TC .	45.VC.
1.00000	99000	01900	0 1000	*000A *	90806	00866	98666
. 72383	.64035	.56184	.49158	.43054	. 93510	.33402	.29644
			PHASE		! ! ! ! ! ! ! ! ! ! ! ! ! ! ! ! ! ! ! !		
	(•			•
2,84353	2,82352	2.79490	2.75573	2.7035A	7 43555	7 54037	00000
2,30514	2.14791	1.97244	1.78817	1.40578	1 40000	70000	048840
.98085	.83861	60.403	5.000.5	010001	35554.1	092/201	1.12373
C1576	20002			670/6	01007	•02000	12660
	76666.	18400	2006	65698	70891	74881	77791
			IMPULSE R	RESPONSE			
.0000	.00204	00081	00260	91100	0000	4100	00000
.00202	•00454	00252	00530	20500	11400	20100	W00000
.00433	.00815	00521	R\$600-	0000			
00978	.01670	- 01 30A	00120		01110	つこうつ・	0+510
20403	10000		AD730.	17610.	9+150.	03425	• 05570
60000	100620	60825.	.52735	.05828	.08366	.00326	00757
366100	0.030.	20400	.00648	00507	00557	.00479	.00596
14500.	-* 00397	.00280	.00290	• 00225	-,00205	00169	30100
00123	00050	.00080	00013	00038	08000	10000	25.00.

		301	*	CHANNEL 1		ī	
		RECEIVED	D BASEBAND	CHANNEL S	SIGNAL		
.00847	.01193	-,08798	11875	26076	-,39839	28052	42325
29210	43659	26767	(1)	27563	41208	22731	34139
-,14944		.08289	.12801	00231	.01881	07703	14070
13960	.20892	.21205	.32841	.08130	13657	10511	17524
05339	07959	06796	10818	.16613	.25137	, ú7551	13907
04148	08386	.01986	.03602	.02943	•0360 •	11166	.18218
-,11115	16272	09977	17035	02642	02732	.02188	.01937
.20313	31561	06/90.	.11112	.04963	.05464	.19959	.30362
.10265	17197	07132	12102	.00260	00422	.04993	.08214
.06895	.10110	.11181	.16695	17221	.25675	15526	.23831
.13479	.19640	.08195	13295	06987	11088	04663	07827
01470	01637	04274	06068	05478	-,09055	.08929	.12919
15547	.24535	.07524	.11568	68600.	61900.	.07057	.10274
.00485	.01959	00351	02626	16641.	.23893	03773	04550
-, 13091	21434	.05120	.06457	.22540	.35849	.02663	.05138
-,10793	18000	02308	04028	00471	.00646	09783	15190
00118	01087	.11824	.17845	.23849	.36589	.03721	.07134
04638	0+160-	• 05809	.09888	.01606	.01834	15516	.23089
.18938	.29128	.09543	.14825	.04675	.05481	.04506	. 08705
24603	-,37554	18161	28297	22544	32880	- .08539	14134
-,03555	03154	02204	05645	15622.	.35332	16961.	.304B3
.17575	.25574	.21849	, 32225	.27425	.41530	.20144	.30526
.11558	.17135	.04312	• 05925	.06021	91680.	-,03489	03772
22600	-,34868	07481	13204	.10777	.18140	.09618	13967
.18703	.28474	.04507	.07384	00320	01977	.12053	.17423
.22260	.34763	.08796	.13251	.12539	.17642	.06062	.103/1
.02106	.01751	.00915	.02791	04048	07984	.14975	.23414
.04370	.07528	07432	*6601*-	20154	-,31601	.0000	.08045
.04972	.10826	12999	21374	00950	01869	00429	.00152
.04352	.05600	.15676	.24077	.08923	.14143	50110.	.00983
• 04556	.06050	.13270	60107	1901.	.28255	.21922	.33888
01690.	.10139	.07820	.10877	00166	.01033	-,05730	10576

	`*						
		RECEIVED	BASEB	PORT SIGNAL	VAL		
.00847	.01193	08798	11875	-,26076	39839	28052	4232
29210	 43659	26767	39807	27563	41208	2273	34139
14944	23127	.08289	.12801	0023i	.01881	07703	1.041
_	.20892	•21205	.32841	.08130	13657	10511	17524
05339	07959	06796	~	•	.25137	07551	1390
04148	08386	.01986	·O	.02943	, 03604	11166	18216
111115	-,16272	9	$\overline{}$	02642	02732	.02188	.0193
.20313	(~)	06/90.	.11112	.04963	.05464	.19959	.3036
.10265	19171.	07132	12102	.00260	00422	6640.	.0821
.06895	.10110	.11181	.16695	17271.	.25675	,15526	.2383
.13479	.19640	.08195	13295	06987	11088	04663	07821
01470	01637	04274	06068	05478	09055	.08929	1621.
.15547	.24535	.07524	.11568	68600.	.00679	.07057	.1027
.00485	.01959	00351	02626	14997	. 23893	03773	0455
13091	21434	.05120	.06457	.22540	.35849	. 02663	.0513
10793	œ	02308	04028	00471	90000	09783	1519
00118	01087	.11824	.17845	.23849	.36589	.03721	.0713
04638	09740	60850.	98860.	.01606	.01834	15516	.2308
.18938	.29128	.09543	.14825	•04675	.05481	.04506	.0870
24603	-,37554	18161	28297	22544	328B0	08539	1413
03555	03154	Q.	05645	.22957	.35332	19691	.3048
.17575	.25574	.21849	.32225	.27425	.41530	.20144	.3052
.11558	.17135	.04312	.05925	.06021	.08916	03489	0377
22600	-,34868	07481	13204	.10777	.18140	.09618	1396
.18703	.28474	.04507	.07384	00320	01977	.12053	.1742
.22260	.34763	96180.	13251	.12539	.17642	.06062	.1037
.02106	.01751	.00915	.02791	8+0+0*-	+8610°-	.14975	.2341
.04370	.07528	07432	10994	20154	-,31801	.0000	. 08045
.04972	.10826	12999	21374	05600*-	01869	00429	.00152
.04352	.05600	.15676	.24077	.08923	.14143	.01105	.8600°
.04556	.06050	.13270	.20109	19011	25	.21922	.3388
06010	101	06060	10000	***	•		•



Representative Main and Auxiliary Baseband Channel Amplitude Responses Figure 3-4.

3.3 Program Library Catalog

In order to facilitate the use of the subroutine library being developed under the present contract, it has been useful to create a library catalog for easy user reference. The two pages that follow contain an alphabetized list of programs developed to date including author(s), date originated and revised.

The availability of this library catalog has already been found useful in the present contractual effort. As programs are generated, qualified and subsequently revised, the users of the library become readily aware of the progress being made. When Motorola delivers the software to be developed under the present effort, this cross reference will also be useful to RADC, especially if multiple users are envisioned.

3.4 Program Validation

Although the signal generation program has been developed very methodically leaving very little room for error, it nevertheless makes sense, whenever possible, to provide an independent check before proceeding with the next stage of the effort. In the present case, an existing BCR processing program has been used to assure the validity of the port signals generated by SIGGENO.

Figure 3-5 shows cancellation performance for the single interference example described in the output file in Section 3.2.5. More specifically, Figure 3-5(a) shows the sample-and-held amplitude envelope at the main antenna port while Figure 3-5(b) shows the corresponding envelope of the combined signal after cancellation. A detailed explanation of the BCR adaptive process used to obtain this cancellation will be given in a subsequent project memorandum. For the moment, it suffices to show that the port signals generated by SIGGENO appear to be valid. At least three other cases have been examined and their successful results have served to insure against pathological validation.

The validity of SIGGENO has been further reassured via Figure 3-6 which shows the center-frequency main-antenna and composite-antenna field patterns evaluated over a 0.25° azimuth range about the incident interference at 45°. A 38 dB cancellation may be noted.

In Figure 3-6, the double-null pattern about 45° may justifiably arouse the reader's curiosity. For the moment, it can be said that this phenomenon must be associated with the antenna aperture dispersion over the 0.1% RF bandwidth, since no other channel mismatch condition has been introduced in the present example. Interestingly, the BCR process (which is capable of scanning the eigenspace of the auxiliary-signal 4x4 covariance matrix, C) has revealed the existence of two nontrivial eigenvalues. This fact is demonstrated in Figure 3-7 showing a two-step evolution of the four adaptive weights. Here, the four complex weight-vector components have been initially set to zero, the origin of the common complex plane shown. Two BCR iterations are clearly observable.

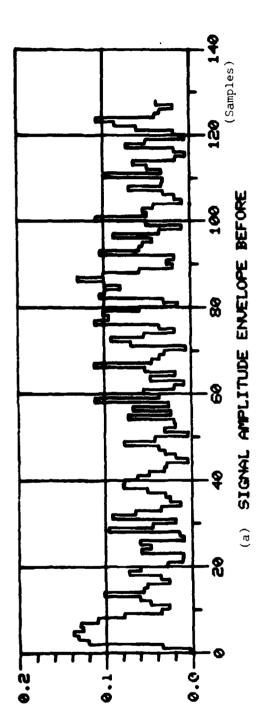
To test the existence of a second non-trivial eigenvalue of C, the BCR process was inhibited to a single iteration. A single-null composite pattern resulted with a depth of about 42 dB. An additional 10 dB of suppression was obtained after the second iteration. Clearly, C possesses a second, though relatively small eigenvalue, despite the fact that only one interference is involved. This topic will be discussed further in subsequent investigation.

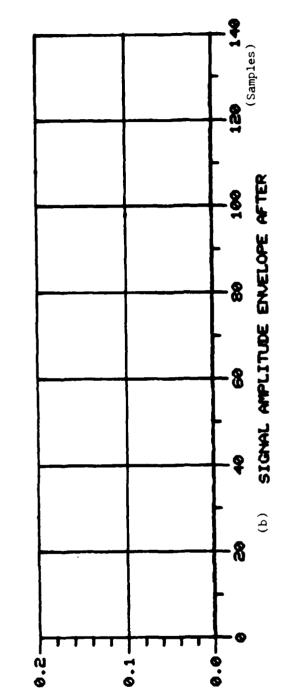
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Original Main-Port and Combined-Port Signal Amplitude Envelope Before and After Cancellation Using BCR Adaptive Processing Figure 3-5.

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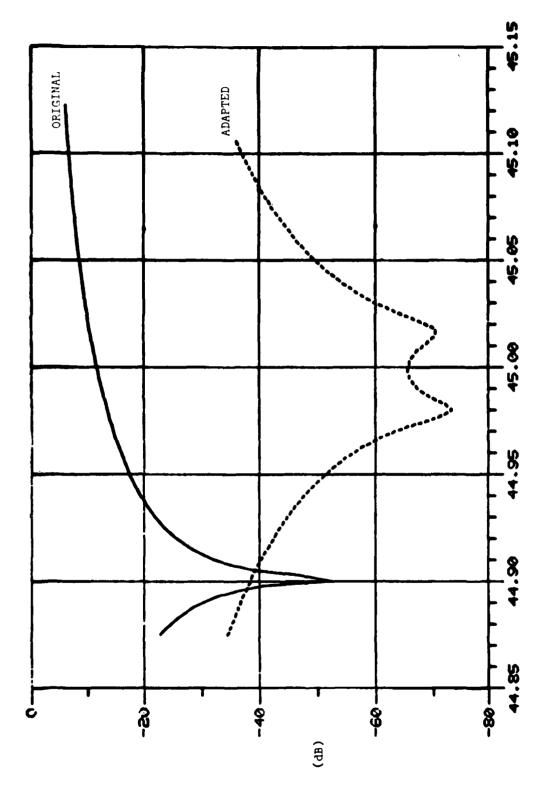


Figure 3-6. Original Main-Port and Adapted Combined-Port Center-Frequency Field Patterns

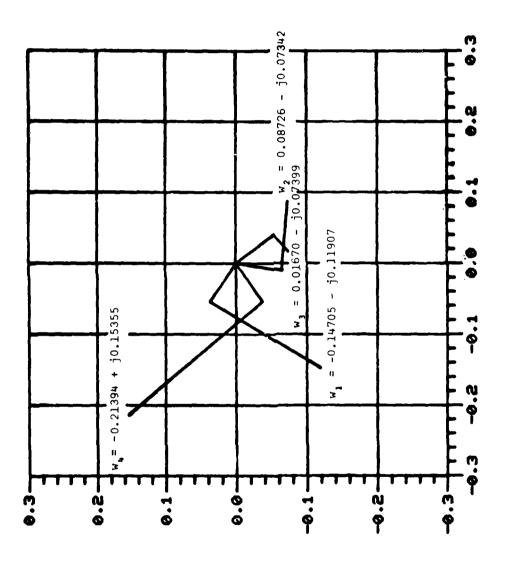


Figure 3-7. Evolution of Adaptive BCR Weights in Complex Plane

4.0 CONCLUSIONS AND RECOMMENDATIONS

The present project memorandum has been devoted to describing, in some detail, the development of a minimum-core signal generation program, a program for generating sampled baseband signals at each port of a multiport antenna system. Motivated by the underlying mathematical model defined in Project Memorandum 8512-01, Section 2.0 provides a specific parametric system description based on a normalized model amenable to easy generalization and suitable for computer simulation.

Section 3.0 discusses the actual development of the signal generation program, SIGGENO. First, the general methodology of a modularized program architecture is given in Section 3.1. Following this, a stage-by-stage specific program development in Section 3.2 begins with the description of the input data file consisting of a very readable table of pertinent system parameters. Presented subsequently, is the complete library of source subroutine modules comprising the virtual source signal generation program, SIGGENO:S, their functional description in connection with a minimum-core program architecture and a complete FORTRAN listing of each. The corresponding library of binary modules is introduced along with two special job control language programs, JCL:B and JCLSIGO:BL, the first for creating individual binary modules and the second for concatenating them into the composite binary module SIGGEN0:B while simultaneously generating an executable load module SIGGENO:L. Section 3.2 ends by defining the procedure for executing SIGGENO:L, via job control program JCL:EX, and the formation of an output file, SIGGENO:0, for a specific example. Using an existing BCR adaptive processing program, the validation of SIGGENO is established beyond reasonable doubt.

The minimum-core architecture adopted for the signal generation program is crucial in generating data for a large-scale system. However, because of some inherently necessary redundancy, the present version is not time-optimal. Upon completing and qualifying the present version of the signal generation program, a limited effort was directed toward defining an alternative program structure that would possess both a minimum-core and a minimum time characteristics. A three-stage partitioning seemed to be the logical approach to take. The first stage was devoted to generating the sequence of sampled noise signal envelopes and storing them in a data file. Of course, this circumvented the need to regenerate this data for each port, which is unavoidably done in SIGGENO. The second stage was designed to simply generate the impulse responses of each and every channel associated with each and every port and output them into another data file. With the incident noise and impulse response data files at hand, these two stages of the alternate version of the signal generation program need not be run unless the maximum system dimensionality and/or system description needs to be changed. The third stage of the new program version, SIGGEN1, was constructed to generate a selected set of port signals from a selected set of incident noise sources. With this capability, several examples could be created by SIGGEN1 using the same two data files. However, because of the I/O burden required in the third stage, the speed advantage noted to date has been meager. Based on comparative speed performance for at least two isolated examples, there does not seem to be any substantial justification for adopting this alternate three-stage signal generation program architecture. For the time being, SIGGENO will be the preferred program version.

A possible future effort toward time-optimization of the signal generation program might be one involving a two-stage program formulation. The first stage could be designed to generate individual channel signals associated with each port. The second stage could simply involve the selected superposition of a subset of channel signals over a selected subset of port signals, generating thereby, a number of varying examples from one set of data generated in the first stage.

Other possible variations or additions to the existing signal generation program could be the generation of multipath and multitap signals. In both cases, the basic program will remain substantially intact. Subroutines SIGSETO and PRTSGNLO will require an appropriate number of new call statements. However, the functional aspects associated with multipath and multitap signals and thus the major burden thereof will be relegated to dedicated subroutine modules consistent with the overall program architecture employed.

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- [1] Daniel, S. M., "BCR Adaptive Processing Mathematical Model," Project Memorandum 8512-01, March 15, 1980.
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BATCH ADAPTIVE PROCESSING AND THE BCR PROCESS

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1.0 INTRODUCTION

BCR is an acronym for "Batch Covariance Relaxation" which was coined at Motorola's Government Electronics Division in connection with the development of a proprietary digital multisensor adaptive processor based on a minimum-mean-square (MMS) criterion [1]. The term "Batch" is intended to emphasize the batch mechanization embodying the suitable underlying process and distinguish it from a dynamic alternative. More specifically, this term refers to the fact that the underlying process is designed to operate on the multisensor sampled signal data in batches which are distinct but contiguous and of sufficient duration so as to allow for the necessary computational time of the process. In particular, the batch duration is chosen long enough so as to allow for the derivation of adaptive weights that will provide the optimal combination of multisensor data within the batch, in accordance with the MMS criterion. It should be understood that the adaptive weights derived from a multisensor signal data-batch must be applied to that very batch, if the full advantage of the batch approach is to be realized, in general.

The term "Covariance" refers to the computation of the covariance matrix computed over a batch of multisensor sampled signal data which are to be adaptively weighted. Such a matrix often arises in a variety of parameter estimation problems based on the MMS criterion. A large group of such problems gives rise to a system of linear equations

$$C\underline{w} + \underline{b} = \underline{0} \tag{1-1}$$

where C is, in general, an N x N complex conjugate-symmetric covariance matrix, \underline{b} is a complex N-vector contained in the space generated by C and \underline{w} is the complex adaptive weight N-vector to be determined.

The term "Relaxation" refers to the nature of the computational method used to solve for a \underline{w} that satisfies (1-1). The specific relaxation method used is the well-known Conjugate Gradients (CG) method, a numerically efficient, stable, finite-step, iterative descent procedure, a special case of the more general Conjugate Directions (CD) method [2].

Section 2.0 presents the Batch Adaptive Process in the context of an adaptive array sidelobe cancellation subsystem. Following a batch formulation of the underlying adaptive array problem, two alternative solution approaches are considered. The Batch Covariance Inversion (BCI) approach, more commonly referred to as Sample Matrix Inversion (SMI), is discussed briefly in order to provide a familiar background to the informed reader. Basically, BCI encompasses all techniques capable of producing a solution to (1-1) via an explicit inversi of the covariance matrix C. Since the existence of a direct inverse, C⁻¹, may not generally be guaranteed, one may be compelled to resort to covariance regularization and thus rely on the approximate regularized inverse, C⁻¹, at the expense of some error in the solution. Alternatively, whether or not C is full-rank, a pseudoinverse, C⁺, may be constructed which will produce the unique minimum-norm solution to (1-1).

In contrast to BCI, the BCR approach, which encompasses all variations of the CD method, will produce the solution to (1-1) without inversion. In particular, the CG method, which is the main thrust of the present investigation, is designed to produce the minimum-norm solution to (1-1). Under certain conditions, it is possible to use the CG process to construct C^{-1} , if it exists. Considering that the algorithmic structure of the CG method lends itself to an architectural implementation that is considerably more efficient than that of any inversion procedure, (such as the standard or modified Cholesky Decomposition and the Singular Value Decomposition) it is highly recommended for batch adaptive processing. In large-scale applications when the dimensionality of C may exceed 100, a BCI approach will be vulnerable to roundoff error and, as a consequence, its operational effectiveness may deteriorate. It is here where the BCR approach clearly excels. Specifically, the CG method begins from an initial solution estimate, w^0 , and iteratively generates improved estimates \underline{w}^1 , \underline{w}^2 , ... until it terminates after, at most, N iterations, the dimensionality of system (1-1). If we wish to diminish the roundoff error in this final estimate, we simply consider it as an initial estimate and repeat the CG process, thereby producing a more refined estimate of the minimum-norm solution to (1-1).

Section 2.0 concludes with a block-diagram functional description of a batch adaptive processor.

Section 3.0 provides the mathematical basis of the BCR adaptive process. Included here is a detailed development of the general CD method followed by a similar development of its most efficient special case, the CG method. Subsequently, some of the important properties of the CG method are discussed. Finally, two numerical examples are given that demonstrate the validity of the methods discussed and provide a tangible insight into their properties.

Section 4.0 discusses the important extension of BCR to the linear-equality-constrained MMS problem in the context of adaptive array processing. Following a Lagrange-multiplier formulation of the underlying problem the mathematical development of the constrained BCR (CBCR) formulation is presented. Both the general constrained CD (CCD) and the special constrained CG (CCG) methods are derived. Numerical examples serve to illustrate the validity of the various formulations discussed. Finally, the application of CBCR to adaptive beamforming is noted to be particularly important when the covariance matrix inverse, C⁻¹, does not exist and the use of the pseudoinverse, C⁺, is not valid.

2.0 BATCH ADAPTIVE PROCESSING

The concept of batch adaptive processing is presented in the context of an adaptive array sidelobe cancellation subsystem. A mathematical formulation of the underlying MMS parameter estimation problem leads to the special linear system of equations (1-1). Alternative approaches for solving (1-1) fall into two distinct categories; namely, inversion and relaxation. The inversion approach is examined briefly in order to add perspective to the relaxation approach which happens to be the main thrust of the present effort. In particular, the effort will be devoted to the investigation of the conjugate gradients (CG) method [2]. The primary motive for choosing this technique is that it happens to be a numerically robust and efficient procedure for solving (1-1) possessing, at the same time, a structure that lends itself to a number of architecturally-efficient, technically-reliable and cost effective implementations. A functional block diagram of the general batch adaptive processor is given.

2.1 Mathematical Formulation

Consider an adaptive array sidelobe cancellation subsystem consisting of a main narrow-beam low-sidelobe Taylor-weighted linear antenna array in combination with N omnidirectional weight-adjustable auxiliary antenna elements nonuniformly emplaced over the main-array aperture. The purpose of this arrangement is to suppress undesired sidelobe interference by appropriate auxiliary-weight adjustment. More specifically, the sidelobe interference assumed will consist of directionally-distinct continuous or pulsed wideband noise sources.

Project Memorandum 8512-01 [3] has already described an appropriate mathematical model for generating complex baseband signal samples received at the main and auxiliary ports of the system described above, due to a specified number of incident noise sources. The pertinent signals involved are defined to be

- s₀(m) = the m-th sample of the complex baseband scalar signal received at the main-antenna port

Letting

we may define the combined-port signal by

$$s_c(m) = \underline{s}^T(m)\underline{w}(m) + s_0(m)$$
 (2-1)

= the m-th sample of the received complex baseband combined scalar signal resulting from the combination of the main-port signal and the weighted sum of the N auxiliary signal components during the m-th sample time interval

Based on physically meaningful arguments, the typical criterion of an adaptive array process is the familiar MMS criterion, or, more specifically, the minimum-combined-power criterion. In more precise terms, we wish to determine the weight vector $\underline{\mathbf{w}}(\mathbf{m})$ which minimizes a convenient metric of combined power. Symbolically, this may be stated as

$$\min_{\mathbf{w}(\mathbf{m})} \mathbf{P}_{\mathbf{c}}(\underline{\mathbf{w}}(\mathbf{m})) \tag{2-2}$$

where

The same of the sa

$$P_{c}(\underline{w}(m)) = ||s_{c}(m)||^{2}$$

= the combined signal power, a metric which must be defined in a manner suitable to the adaptive process employed

A continuous or dynamic adaptive process based on criterion (2-2) is designed to produce a new weight-vector value $\underline{w}(m)$ with each new set of signal samples $\{s_0(m), \underline{s}(m)\}$. Accordingly, a convenient combined-power metric is the exponential running average

$$P_c(\underline{w}(m)) = \rho P_c(\underline{w}(m-1)) + (1-\rho)|s_c(m)|^2$$
 (2-4)

and the corresponding samplewise weight-adjustment is of the general form

$$\underline{w}(m) = \underline{w}(m-1) + \Delta w(m) \tag{2-5}$$

where the specific form of $\Delta w(m)$ is peculiar to the actual dynamic adaptive process employed.

Given a temporally-stationary interference environment, a dynamic adaptive process will direct the evolution of the adaptive weight vector toward a steady-state value which will suffice to minimize the combined power henceforth. Depending on the bandwidth implied by ρ in (2-4), the nature of the actual adaptive process used and the interference environment, the convergence-time of the weight-vector, from an arbitrary initial value to its final steady-state value, will vary. Clearly, in the case of a stationary environment, the length of the convergence-time is of little consequence. However, convergence-time becomes important when the dynamic adaptive process has to deal with a nonstationary dynamically-changing environment. Depending on the nature of the nonstationarity, the performance of a given dynamic adaptive process could degrade considerably, to the point where it may become operationally ineffective.

Whereas a given dynamic adaptive process is vulnerable to a nonstationary environment [4], a batch process is designed to circumvent the central cause of this vulnerability: the dependence on convergence-time. In contrast with a dynamic process, a batch approach is designed to operate on a batch of signal data, of an appropriate number of samples, with a unique weight-vector value which minimizes the combined power within the batch. The tacit assumption here is that the underlying weight-estimation process terminate within the available batch-time. By its very nature, the batch approach is not affected by signal dynamics outside the bounds of the given batch it happens to be operating on. On the other hand, signal dynamics within the batch will appear "frozen," exhibiting, at worst, an increased dynamic range in signal values. As such, suppression of undesired interference signals within the batch will depend on their average power within the batch. In any case, transient effects that may be present in a dynamic approach will be absent in a batch approach. Consequently, convergence-time has no meaning in a batch process. Instead, what is significant here is batch-time or response-time, the time needed by the underlying weight-estimation process to produce or respond with an optimal weight vector for a given batch. Of course, the batch-time must be sufficiently long so that the statistical characteristics of the signal process may be adequately observed.

The batch formulation of the adaptive array problem described above can be made more precise, in mathematical terms, after defining some important pertinent quantities. Let

$${s_0(m)}_{m=1}^{M} = an M-sample main-port complex baseband scalar signal batch$$

[{]s(m)} M = the corresponding M-sample complex baseband
N-vector signal batch whose components
represent the individual auxiliary-port
signals

w = a constant complex adaptive weight N-vector
applied componentwise to the auxiliary-port
N-vector signal, s(m), for m=1, ..., M

whence,

$$\left\{ s_{c}(m) \right\}_{m=1}^{M} = \left\{ \underline{s}^{T}(m)\underline{w} + s_{0}(m) \right\}_{m=1}^{M}$$
 (2-6)

= the M-sample complex combined-port baseband scalar signal batch

Then, using compact Hilbert-space notation, we may define the appropriate combined-power expression for a batch approach by

$$P_{c}(\underline{w}) \equiv \|s_{c}\|^{2} \tag{2-7}$$

which, by (2-6), is the average power of the combined signal over the M-sample batch. Note that $P_C(\underline{w})$ is a positive-real scalar quadratic function of the complex N-vector \underline{w} . As such, $P_C(\underline{w})$ will attain a minimum value at some point \underline{w} , which need not necessarily be unique. From calculus we know that at such a minimum point the gradient of $P_C(w)$ with respect to \underline{w} must necessarily vanish. More specifically, we wish to determine \underline{w} for which

$$\begin{bmatrix} \nabla_{\underline{\mathbf{w}}_{\mathbf{r}}} \\ \nabla_{\underline{\mathbf{w}}_{\mathbf{i}}} \end{bmatrix} \mathbf{P}_{\mathbf{c}}(\underline{\mathbf{w}}) = \begin{bmatrix} \underline{\mathbf{0}} \\ \\ \underline{\mathbf{0}} \end{bmatrix}$$
 (2-8)

or, more symbolically,

$$\nabla_{\underline{\mathbf{W}}} P_{\mathbf{C}}(\underline{\mathbf{w}}) = \underline{0} \tag{2-9}$$

†Given complex-valued time-sequences $x = \{x(m)\}_{m=1}^{M}$ and $y = \{y(m)\}_{m=1}^{M}$, define their inner-product by

$$\langle x,y \rangle = \frac{1}{M} \sum_{m=1}^{M} x^{\pm}(m)y(m)$$

and the metric of a given sequence as its self inner-product

$$||x||^2 = \langle x, x \rangle$$

where we arbitrarily define the complex gradient operator [5] by

$$\nabla_{\underline{\underline{w}}} = \nabla_{\underline{\underline{w}}_{\underline{r}}} + j\nabla_{\underline{\underline{w}}_{\underline{i}}}$$
 (2-10)

In view of (2-6), and definitions

$$s_0 = s_{or} + js_{oi}$$

$$s_c = s_{cr} + js_{ci}$$

$$\underline{s} = \underline{s}_r + j\underline{s}_i$$

$$\underline{w} = \underline{w}_r + j\underline{w}_i$$
(2-11)

(2-7) may be rewritten as

$$P_{c}(\underline{w}) = \langle s_{c}, s_{c} \rangle$$

$$= \langle 1, s_{c}^{*}s_{c} \rangle$$

$$= \langle 1, (s_{cr})^{2} + (s_{ci})^{2} \rangle$$

$$= \langle 1, (\underline{s}_{r}^{T}w_{r} - \underline{s}_{i}^{T}w_{i} + s_{qr})^{2} + (\underline{s}_{r}^{T}w_{i} + \underline{s}_{i}^{T}w_{r} + s_{qi})^{2} \rangle \qquad (2-12)$$

whence, by (2-10), we get

$$\nabla_{\underline{\mathbf{w}}}^{\mathbf{P}_{\mathbf{c}}}(\underline{\mathbf{w}}) = \langle \mathbf{1}, (\mathbf{s}_{\mathbf{r}}^{\mathsf{T}} \mathbf{s}_{\mathbf{cr}} + \mathbf{s}_{\mathbf{i}}^{\mathsf{T}} \mathbf{s}_{\mathbf{ci}}) + \mathbf{j} (\mathbf{s}_{\mathbf{r}}^{\mathsf{T}} \mathbf{s}_{\mathbf{ci}} - \mathbf{s}_{\mathbf{i}}^{\mathsf{T}} \mathbf{s}_{\mathbf{cr}}) \rangle$$

$$= \langle \mathbf{1}, Re \left\{ \underline{\mathbf{s}}^{\mathsf{T}} \mathbf{s}_{\mathbf{c}} \right\} + \mathbf{j} Im \left\{ \underline{\mathbf{s}}^{\mathsf{T}} \mathbf{s}_{\mathbf{c}} \right\} \rangle$$

$$= \langle \mathbf{1}, \underline{\mathbf{s}}^{\mathsf{T}} \mathbf{s}_{\mathbf{c}} \rangle$$

$$= \langle \underline{\mathbf{s}}, \mathbf{s}_{\mathbf{c}} \rangle \qquad (2-13)$$

which is simply a cross-correlation of the complex auxiliary signal N-vector \underline{s} with the combined complex scalar signal s_c ; clearly, a complex N-vector. Using (2-6), it is possible to simplify (2-13) into an expression that involves \underline{w} explicity; that is,

$$\nabla_{\underline{W}} {}_{\underline{C}}(\underline{w}) = \langle \underline{s}, s_{\underline{C}} \rangle$$

$$= \langle \underline{s}, \underline{s}^{T} \underline{w} + s_{\underline{O}} \rangle$$

$$= \langle \underline{s}, \underline{s}^{T} \rangle \underline{w} + \langle \underline{s}, s_{\underline{O}} \rangle$$

$$= C\underline{w} + \underline{b} \qquad (2-14)$$

where

$$C = \langle \underline{s}, \underline{s} \rangle$$
 (2-15)

= the complex N x N conjugate-symmetric <u>covariance matrix</u> of the complex auxiliary N-vector signal, <u>s</u>, over the batch of M samples. Its general component is given by

$$C_{ij} = \frac{1}{M} \sum_{m=1}^{M} s_{i}^{*}(m) s_{j}^{*}(m)$$
 (2-16)

$$\underline{\mathbf{b}} = \langle \underline{\mathbf{s}}, \ \mathbf{s}_0 \rangle \tag{2-17}$$

= the complex N-vector representing the <u>cross-correlation</u> between the complex auxiliary N-vector signal, <u>s</u>, and the complex main scalar signal, s_Q. Its general component is given by

$$b_{i} = \frac{1}{M} \sum_{m=1}^{M} s_{i}^{*}(m) s_{0}(m)$$
 (2-18)

As a consequence of (2-14) the minimum-combined-power condition (2-9) leads to the complex linear system of equations

$$C\underline{w} + \underline{b} = \underline{0} \tag{2-19}$$

involving the unknown complex weight N-vector \underline{w} . The section that follows discusses possible solutions to (2-19).

2.2 Solution Alternatives

Methods for solving (2-19) fall into a number of distinct categories including inversion and relaxation. To denote the association with batch processing and an accompanying covariance matrix, these two categories will

be suggestively referred to by the names "Batch Covariance Inversion" (BCI) and "Batch Covariance Relaxation" (BCR). Although the emphasis of the present effort is exclusively on the conjugate gradients (CG) method, a relaxation technique, a brief examination of inversion will provide a useful perspective for understanding some essential aspects of the CG method.

2.2.1 Batch Covariance Inversion (BCI)

Formally, the solution to (2-19) is simply

$$\hat{\underline{\mathbf{w}}} = -\mathbf{C}^{-1}\underline{\mathbf{b}} \tag{2-20}$$

assuming that the inverse of the covariance matrix, C^{-1} , exists. In general, C may be numerically ill-conditioned or even singular with rank less than N. Since C^{-1} may not exist under these conditions, one is compelled to seek either an approximate or a more generalized form of C^{-1} .

2.2.1.1 Regularized Inverse

Given a singular matrix C, it is possible to construct a full-rank approximate version, \tilde{C} , by augmenting C with a sufficient amount of diagonal variance; i.e.,

$$\tilde{C} = C + \varepsilon I \tag{2-21}$$

where $\varepsilon > 0$ is a small fraction of the largest diagonal element in C. \tilde{C} is referred to as a <u>regularization</u> of C. The approximate solution of (2-18) is then

$$\frac{\tilde{\mathbf{w}}}{\tilde{\mathbf{w}}} = -\tilde{\mathbf{c}}^{-1}\underline{\mathbf{b}} \tag{2-22}$$

where \tilde{C}^{-1} is the regularized inverse. Clearly, the accuracy of \tilde{w} with, respect to satisfying (2-19) will depend directly on the magnitude of ε .

It is interesting to note here that ε may be viewed as the common variance of independent additive white noise processes associated with each auxiliary signal component of \underline{s} and main signal \underline{s}_a .

2.2.1.2 Pseudoinverse

Let C^N represent the N-dimensional complex space. In general, as \underline{w} spans C^N , $C\underline{w}$ will span a subspace $C^R \subset C^N$ where R = rank C. Then, (2-19) is satisfied by any \underline{w} of the form

$$\tilde{w} = w^{R} + w^{\overline{R}} \tag{2-23}$$

where $\underline{w}^R \in C^R$ is unique and $\underline{w}^R \in \overline{C^R} = C^N - C^R$ is arbitrary. By construction,

$$\underline{0} = \underline{C}\underline{w} + \underline{b}$$

$$= \underline{C}(\underline{w}^R + \underline{w}^R) + \underline{b}$$

$$= \underline{C}\underline{w}^R + \underline{C}\underline{w}^R + \underline{b}$$

$$= \underline{C}\underline{w}^R + \underline{b}$$
(2-24)

as expected. As a consequence, a desirable exact solution of (2-19) is

$$\hat{\mathbf{w}} = \mathbf{w}^{\mathbf{R}} \tag{2-25}$$

which happens to be the smallest-length solution of the form (2-23) since \underline{w}^R and \underline{w}^R are mutually orthogonal. Solution (2-25) is referred to as the minimum-norm solution of (2-19).

Solution (2-25) may be obtained by using a unique special inverse operator, C⁺, known as the <u>pseudoinverse</u> of C [6]. One construction of C⁺ is given in the specialized theorem that follows.

Theorem 2-1. [Pseudoinverse of a Hermitian Matrix]

Let C be an N \times N complex Hermitian (conjugate symmetric) matrix with rank R \leq N. Given its similarity transformation

$$C = E \Lambda E^{*T}$$
 (2-26)

where

$$\mathbf{E}^{-1} = \mathbf{E}^{\pm \mathbf{T}} \tag{2-27}$$

and, as such,

$$\|Ez\|^2 = \|z\| \tag{2-28}$$

indicating that E preserves the Euclidean norm of any N-vector it operates on.

 Λ = an N x N real diagonal matrix whose diagonal elements are the eigenvalues of C. Note that when R < N, N-R eigenvalues of C are identically zero. An appropriate form of Λ is

Then, the pseudoinverse of C is given by

$$C^{\dagger} = E \Lambda^{\dagger} E^{\dot{x}^{\dagger}}$$
 (2-30)

where

$$\Lambda^{+} = \begin{bmatrix} \Lambda_{11}^{-1} & 0 \\ 0 & 0 \end{bmatrix} = \begin{bmatrix} \lambda_{1}^{-1} \\ \ddots \\ \lambda_{R}^{-1} \\ 0 & \ddots \\ 0 \end{bmatrix}$$
 (2-31)

= the pseudoinverse of Λ

$$\|z\| = \sqrt{\sum_{n=1}^{N} z_n^{*} z_n}$$

which represents its length.

The Euclidean norm of any vector $\underline{z} \in C^{N}$ is defined by

and the minimum-norm solution of (2-19) is given by

$$\frac{\hat{\mathbf{w}}}{\mathbf{v}} = -\mathbf{c}^{\dagger}\underline{\mathbf{b}} \tag{2-32}$$

Proof: Consider (2-19) and define the residual vector

$$\underline{\mathbf{r}} = C\underline{\mathbf{w}} + \underline{\mathbf{b}} \tag{2-33}$$

We wish to determine \underline{w} which will minimize the Euclidean norm of this residual. Then, writing

$$\|\mathbf{r}\|^{2} = \|\underline{\mathbf{C}}\underline{\mathbf{w}} + \underline{\mathbf{b}}\|^{2}$$

$$= \|\underline{\mathbf{E}}\Lambda\underline{\mathbf{E}}^{*T}\underline{\mathbf{w}} + \underline{\mathbf{b}}\|^{2}$$

$$= \|\underline{\mathbf{E}}(\Lambda\underline{\mathbf{E}}^{*T}\underline{\mathbf{w}} + \underline{\mathbf{E}}^{*T}\underline{\mathbf{b}})\|^{2}$$

$$= \|\Lambda\underline{\mathbf{E}}^{*T}\underline{\mathbf{w}} + \underline{\mathbf{E}}^{*T}\underline{\mathbf{b}}\|^{2}$$
(2-34)

which follows by property (2-28). Now, define the following two vectors

$$E^{*T}\underline{w} = \underline{w} = \begin{bmatrix} \underline{u} \\ \underline{v} \end{bmatrix}$$
 (2-35)

$$\mathbf{E}^{\dagger T} \underline{\mathbf{b}} = \underline{\boldsymbol{\beta}} = \begin{bmatrix} \underline{\mathbf{d}} \\ \underline{\mathbf{e}} \end{bmatrix}$$
 (2-36)

where $\underline{\omega}$ is shown to be a concatenation of \underline{u} and \underline{v} representing the first R components and the remaining N-R components of $\underline{\omega}$, respectively. A similar partitioning of $\underline{\beta}$ is implied in (2-36). Then, upon substituting (2-35) and (2-36) in (2-34), we get

$$\|\underline{r}\|^{2} = \|\underline{\Lambda}\underline{\omega} + \underline{\beta}\|^{2}$$

$$= \|\underline{\Lambda}_{11}\underline{u} + \underline{d}\|^{2} + \|\underline{e}\|^{2}$$
(2-37)

which follows from (2-29). Note that $||\mathbf{r}||^2$ is minimized by any $\underline{\omega}$ of the form

$$\frac{\tilde{\omega}}{\tilde{\omega}} = \begin{bmatrix} \frac{u}{v} \\ \frac{v}{v} \end{bmatrix}$$

$$= \begin{bmatrix} -\Lambda_{11}^{-1} \frac{d}{d} \\ \frac{v}{v} \end{bmatrix} + \begin{bmatrix} \frac{0}{v} \\ \frac{v}{v} \end{bmatrix}$$
(2-38)

where $\underline{0}$ is the R or (N-R)-dimensional zero depending on its location, and \underline{v} is any (N-R) complex vector. Clearly, a unique minimum-norm $\underline{\tilde{\omega}}$ that minimizes $||\underline{r}||^2$ results by choosing \underline{v} = 0. By (2-35), (2-36) and property (2-27), it follows from (2-38) that the general exact solution to (2-19) becomes

$$\frac{\tilde{w}}{\tilde{u}} = E\tilde{\omega}$$

$$= E \begin{bmatrix} -\Lambda_{11}^{-1} \frac{d}{d} \\ 0 \end{bmatrix} + E \begin{bmatrix} 0 \\ \underline{v} \end{bmatrix}$$

$$= -E \begin{bmatrix} \Lambda_{11}^{-1} & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \underline{d} \\ \underline{e} \end{bmatrix} + E \begin{bmatrix} \underline{0} \\ \underline{v} \end{bmatrix}$$

$$= -E \Lambda^{+} E^{*T} \underline{b} + E \begin{bmatrix} \underline{0} \\ \underline{v} \end{bmatrix}$$

$$= \underline{w}^{R} + \underline{w}^{R} \qquad (2-39)$$

as stated in (2-23). Clearly, by orthogonality of \underline{w}^R and \underline{w}^R , the minimum-norm solution to (2-19) is given by

$$\frac{\hat{\mathbf{w}}}{\mathbf{w}} = -\mathbf{E} \, \mathbf{\Lambda}^{\dagger} \, \mathbf{E}^{\dagger \mathbf{T}} \underline{\mathbf{b}} \tag{2-40}$$

which is identical to \underline{w}^R and is mathematically equivalent to $\underline{E}\underline{\hat{w}}$, where $\underline{\hat{w}}$ is the unique minimum-norm value of (2-38). We have thus proved that there exists an operator

$$C^{+} = E \Lambda^{+} E^{*T}$$
 (2-41)

the pseudoinverse of C, such that

$$\hat{\underline{\mathbf{w}}} = -\mathbf{C}^{\dagger}\underline{\mathbf{b}} \tag{2-42}$$

is the unique minimum-norm solution to (2-19), where, Λ^{\dagger} itself denotes the pseudoinverse of Λ in direct accordance to definition (2-41). Also, it should be clear that when C is full-rank (R=N), $C^{\dagger} = C^{-1}$.

2.2.2 Batch Covariance Relaxation (BCR)

Although the BCI approach is intuitively appealing and there exist a number of numerically-efficient algorithms for computing an "inverse" of the conjugate-symmetric matrix C, the major benefit in deriving an "inverse" is an intended efficient evaluation of a multiplicity of solutions to (2-18) involving a number of distinct forcing vectors, b. However, in the interest of minimizing implementation complexity and insuring reliable numerical performance, especially with increasing dimensionality N, it is imperative that indirect approaches for solving (2-18) be considered. The CG method, a particularly efficient special case of the general class of CD methods is inherently a numerically-robust, finite-step, iterative relaxation technique for producing the minimum-norm solution to (2-18) without the need for explicity computing an "inverse." However, if necessary, it is possible to compute an inverse operator, CX, as a by-product of the CG process[†], which, under certain conditions, happens to be the desired pseudoinverse, C[†].

2.2.2.1 Method of Conjugate Directions (CD)

The origin of the CG method may be traced back to the independent investigations by Maguus Hestenes and Eduard Steifel which culminated in their combined paper [2] in 1952. Both investigators, aware of previous work [7] dealing with the solution of (2-18), recognized that it could be generalized into a category of relaxation techniques that constitute the class of Conjugate Directions (CD) methods. They succeeded in developing the CG method and showing that it is a special computationally-efficient CD method. A detailed mathematical development of the CD and CG methods is deferred to Section ? ?. For the present, a brief outline of the CD method suffices to subsequently introduce the CG method.

An inverse operator, CX, may be defined for any CD method. Under certain conditions, CX is a generalized inverse while under more restrictive additional conditions, it is the unique pseudoinverse, C+.

The general CD method is a finite-step iterative procedure for producing an "exact solution" to the complex linear system (2-19), namely,

$$C\underline{w} + \underline{b} = \underline{0} \tag{2-43}$$

Starting with an arbitrary initial estimate, \underline{w}^0 , the desired solution is obtained by successive optimal relaxation along a special set of search vectors \underline{p}^0 , \underline{p}^1 , ... which satisfy the C-conjugacy (C = orthogonality) property

$$(p^{i}, Cp^{j}) = 0 ; (i \neq j)$$
 (2-44)

More specifically, upon defining the residual vector

$$\underline{\mathbf{r}}^0 = C\underline{\mathbf{w}}^0 + \underline{\mathbf{b}}$$

at the initial estimate \underline{w}^0 , the CD algorithm consists of the following set of recursive steps

$$\alpha_{i} = \frac{(p^{i}, r^{i})}{(p^{i}, cp^{i})}$$
 (2-45.1)

$$\underline{w}^{i+1} = \underline{w}^{i} - \alpha_{i}\underline{p}^{i} \qquad (2-45.2)$$

$$\underline{\mathbf{r}}^{i+1} = \underline{\mathbf{r}}^i - \alpha_i \mathbf{C} \underline{\mathbf{p}}^i \tag{2-45.3}$$

repeated a number of iterations $I \le N$, where N is the dimensionality of system (2-43). Note that the CD procedure terminates in $I \le N$ iterations when $\|\underline{r}\| < \varepsilon \|\underline{b}\|$, a logical stopping criterion. The quantity $\varepsilon << 1$ is chosen commensurate to the computing precision available.

It should be mentioned here that the sequence of C-conjugate vectors, \underline{p}^0 , \underline{p}^1 , ..., may be derived by means of a Gram-Schmidt process. Specifically, employing a complete set of orthonormal N-vectors $\{\underline{e}^1\}_{1=0}^{N-1}$, the Gram-Schmidt (GS) process may be used to generate the set of C-conjugate directions satisfying the conjugacy condition (2-44). As a consequence, the k-th conjugate-direction vector will be given by

The inner-product notation (\cdot, \cdot) is reserved for the vectors in the <u>complex</u> weight N-space, C^N , and must be distinguished from $<\cdot, \cdot>$, the counterpart in time-space.

$$\underline{p}^{k} = \underline{e}^{k} + \sum_{j=0}^{k-1} \beta_{k,j} \underline{p}^{j}$$
 (2-46)

the familiar telescoping form.

2.2.2.2 Method of Conjugate Gradients (CG)

Recall from Section 2.1 that the residual vector, $\underline{\mathbf{r}}^{i+1}$, in (2-45.3) is, in fact, the complex gradient $\nabla_{\mathbf{w}} P_{\mathbf{c}}(\underline{\mathbf{w}})$ evaluated at $\underline{\mathbf{w}} = \underline{\mathbf{w}}^{i+1}$. The CG method is a special CD case where the C-conjugate vectors $\underline{\mathbf{p}}^0$, $\underline{\mathbf{p}}^1$, ... are generated via a built-in GS process using successive gradients at each iteration. In more specific terms, upon defining the residual and conjugate-direction vectors by

$$\mathbf{r}^0 = \mathbf{C} \mathbf{w}^0 + \mathbf{b} \tag{2-47-1}$$

$$\mathbf{p}^0 = \mathbf{r}^0 \tag{2-47.2}$$

the CG algorithm consists of the following recursive steps

$$\alpha_{i} = \frac{(\underline{p}^{i}, \underline{r}^{i})}{(\underline{p}^{i}, \underline{c}\underline{p}^{i})}$$
 (2-48.1)

$$\underline{\mathbf{w}}^{\mathbf{i+1}} = \underline{\mathbf{w}}^{\mathbf{i}} - \alpha_{\mathbf{i}}\underline{\mathbf{p}}^{\mathbf{i}} \tag{2-48.2}$$

$$\underline{\mathbf{r}}^{\mathbf{i+1}} = \underline{\mathbf{r}}^{\mathbf{i}} \sim \alpha_{\mathbf{i}} \mathbf{C} \underline{\mathbf{p}}^{\mathbf{i}} \tag{2-48.3}$$

$$\beta_{i} = \frac{\|\underline{r}^{i+1}\|^{2}}{\|\underline{r}^{i}\|^{2}}$$
 (2-48.4)

$$\underline{\mathbf{p}^{i+1}} = \underline{\mathbf{r}^{i}} + \beta_{\underline{i}}\underline{\mathbf{p}^{i}} \tag{2-48.5}$$

repeated a number of iterations $I \leq N$.

It is important to note here that the successive gradients \underline{r}^0 , \underline{r}^1 , ... may be shown to be mutually orthogonal (or, conjugate) and hence qualify as basis vectors for a GS expansion. The CG method bears its name for this

obvious reason. Above all, the greatest significance of the CG method is in the fact that, as a direct consequence of the particular choice of the basis vectors, the built-in GS process (see (2-47.2), (2-48.4) and (2-48.5)) does not telescope as expected in general. In contrast to the increasing number of terms involved in (2-46), the GS process in the CG method generates the new C-conjugate vector \mathbf{p}^{1+1} from current values of gradient and C-conjugate vectors \mathbf{r}^{1} and \mathbf{p}^{1} , respectively. The computational simplicity of the CG method over that of the general CD method is clear.

2.2.2.3 Intrinsic Inverse

It will be shown in the next section that if $\underline{w}^0 = \underline{0}$, the solution to (2-18) obtained via the general CD method may be written in the form

$$\underline{\hat{\mathbf{w}}} = -\mathbf{C}^{\mathbf{X}}\underline{\mathbf{b}} \tag{2-49}$$

where

$$c^{x} = \sum_{i=1}^{I-1} \frac{p^{i} p^{i * T}}{(p^{i}, cp^{i})}$$
 (2-50)

is a special inverse operator constructed from successive C-conjugate vectors. In general, $C^X \neq C^{\dagger}$. This may be demonstrated via two simple examples given below.

Example 2-1. In system (2-43), let $\underline{b} = \underline{e}^1$, a nontrivial eigenvector of C with associated eigenvalue λ_1 . Starting with an initial solution estimate, $\underline{w}^0 = \underline{0}$, the CG method, (2-48), will yield the exact solution

$$\underline{\hat{\mathbf{w}}} = -\frac{1}{\lambda_1} \underline{\mathbf{e}}^1 \tag{2-51}$$

in a single iteration even if rank C > 1. In this case,

$$c^{X} = \frac{e^{1}e^{1*T}}{\lambda_{1}}$$

$$= E \Lambda^{X} E^{*T}$$
(2-52)

which is the pseudoinverse, C^{\dagger} , only when rank C=1. What is more significant here is that the CG solution, (2-51), is the minimum-norm solution, (2-42), even though $C^{X} \neq C^{\dagger}$. In the sense that C^{X} is tailored to \underline{b} , it may be called the <u>intrinsic inverse</u> of C with respect to \underline{b} . Analogously, Λ^{X} is the intrinsic inverse of the eigenvalue matrix $\overline{\Lambda}$.

Example 2-2. Suppose that, in (2-43), C = I and $\underline{b} = \underline{1}$, the uniform vector. Then, $C^{+} = C^{-1} = I$. Starting with an initial solution estimate, $\underline{w}^{0} = \underline{0}$, the CG method, (2-48), will yield the unique solution

$$\hat{\underline{\hat{w}}} = -\underline{1}$$
 (2-53)

in a single iteration even though C is full-rank. However,

$$c^{\times} = \frac{\underline{b} \ \underline{b}^{*T}}{(\underline{b}, \ \underline{Cb})}$$

$$= \frac{\underline{b} \ \underline{b}^{*T}}{||\underline{b}||^{2}}$$

$$= \frac{1}{N} U \qquad (2-54)$$

where U is the uniform N x N matrix of all 1's and N is the system dimensionality. Clearly, $C^{x} \neq C^{+} = C^{-1}$. We have thus shown that C^{x} is different from C^{-1} , even though the latter exists.

Motivated by these two examples and recalling a number of others where $C^X = C^{-1}$ when the eigenvalues of C are nonzero and distinct, it is intuitively appealing to state the following conjecture conerning a condition under which $C^X = C^{-1}$ might be true.

<u>Conjecture 2-2.</u> [Condition under which the CG Intrinsic Inverse is the Actual Inverse]

In (2-43), let C have distinct nonzero eigenvalues and \underline{b} equal to an exhaustive linear combination of the eigenvectors of C; i.e.,

$$\underline{b} = \sum_{i=1}^{N} a_i \underline{e}^i$$
 (2-55)

where N is the system dimensionality, $a_i \neq 0$ $\forall i \in [1,N]$ and $\{\underline{e}^i\}_{i=1}^N$ is the complete set of eigenvectors of C. Then, the CG intrinsic inverse, C^x , as given by (2-50) is identically equal to the actual inverse, C^{-1} . (2-41).

<u>Comment</u>: By Example 2-1, $C^X \neq C^{-1}$ if <u>b</u> is not exhaustive linear combination of eigenvectors as indicated in (2-55). By Example 2-2, $C^X \neq C^{-1}$ if the eigenvalues of C are identical, independent of the choice of <u>b</u>. This seems to suggest that any multiplicity of eigenvalues of C would lead to a $C^X \neq C^{-1}$. A number of specific numerical examples have substantiated this observation. In fact, the conjecture has held true in a number of examples where the stated hypotheses were satisfied. Of course, the latter observation does not constitute a proof and, as such, the stated condition is a conjecture and not a theorem. The obvious next step is to actually state this conjecture as a theorem and provide a rigorous proof, something beyond the objective of the present work.

An immediate consequence of the above conjecture is the following proposition which intends to guarantee that $C^{X} = C^{-1}$, assuming C^{-1} exists.

Proposition 2-3. [Construction of C-1 Via CG]

Given system (2-19), assume that C has distinct nonzero eigenvalues and let

$$b = C\underline{d} \tag{2-56}$$

where $\underline{d} \in \mathcal{C}^N \ni E^{\star T}\underline{d}$ has no zero elements. Then, the CG intrinsic inverse with respect to \underline{b} is identical to the ordinary inverse.

The reader may be motivated to generalize this proposition by removing this last restriction. It is intuitively appealing to state that, given (2-56), $C^{X} = C^{-1}$ with probability one. The proof of the resulting corollary, if valid, would be much more complex. Note that an event is said to occur with probability one if the occurrence frequency of the complement event is zero.

 $\frac{\text{Comment}}{\text{of C.}}$ Note that, via (2-56), \underline{b} is an exhaustive sum of all the columns of C. Using the similarity transformation for C, (2-56) may be rewritten as

$$\underline{b} = E \Lambda E^{*T} \underline{d} \tag{2-57}$$

Then, assuming that $E^{*T}\underline{d}$ has no zero elements and that Λ is full-rank, $\exists \mid \{a_i\}_i \underline{\mathbb{N}}_1 \in \mathcal{C}^1 \ni \mathbf{n}$

$$a_{i} = \lambda_{i} \sum_{j=1}^{N} d_{j} e_{j}^{*i} \neq 0$$
 (2-58)

and

$$b = \sum_{i=1}^{N} a_i \underline{e}^i$$
 (2-59)

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Then, by Conjecture 2-2, $C^{X} = C^{-1}$.

It should be mentioned, in passing, that Conjecture 2-2 and Proposition 2-3 apply to the general CD method when the C-conjugate vectors involved are contained in the eigenspace of C. This may be guaranteed by construction. However, since the present investigation is primarily focused on the CG method, we will examine the general CD method only to the extent necessary for enhancing the understanding of the CG method.

2.3 Functional Description

Figure 2-1 shows the essential functional blocks that comprise a general batch process as it applies to the specific adaptive array cancellation subsystem discussed in Section 2-1.

As indicated, main and auxiliary-port baseband signal samples, $s_0(m)$ and $\underline{s}(m)$, are presented to a "C and \underline{b} Computation Block" and respective "Delay Memory Buffers." After an M-sample batch-time, C and \underline{b} become available to the "Batch Algorithm Block," which subsequently produces the adaptive weight vector, \underline{w} , in an L-sample period not exceeding the available

batch-time. Then, for an M-sample period of time, \underline{w} is applied onto the auxiliary signal samples comprising the original batch used to compute C and \underline{b} . The resulting weighted auxiliary signal sample sum, $\underline{s}^T(m-M-L)\underline{w}$, is finally added synchronously to corresponding main signal samples, $\underline{s}^{(m-M-L-K)}$, appropriately delayed by K samples to account for the elapsed time through the combiner. The final combined output signal is designated by $\underline{s}_{C}(m-M-L-K-1)$, clearly indicating a processor pipeline delay of M+L+K+1.

It should be mentioned that the minimum value of L is determined by the computation-time of the batch algorithm. A value of L larger than this minimum may be chosen depending on practical considerations. Although C and b must be computed over no less than an L-sample signal batch, larger batches may be used for practical reasons including a potential need to time-share the batch algorithm.

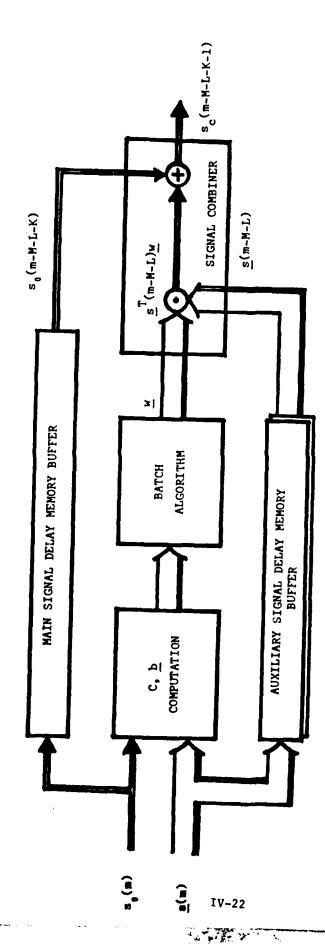


Figure 2-1. Functional Block Mechanization of a General Batch Adaptive Processor Applicable to an Adaptive Array Sidelobe Cancellation System

3.0 MATHEMATICAL BASIS OF THE BCR PROCESS

An appreciation of the BCR process may be derived from a better understanding of its mathematical basis. In this section, a detailed development of the general CD method leads logically to the derivation of the special CG method. Specific numerical examples serve to illustrate the validity and some unique features of the CG method, the relaxation algorithm actually adopted for the BCR process.

3.1 Detailed Mathematical Development

The derivation of the CG method is most clearly motivated from the mathematical development of the general CD method. Accordingly, the CD method is derived first. The CG method is developed subsequently as a special case of the general CD method. Before proceeding, however, some preliminary remarks are in order.

Recall that the batch formulation of the adaptive array problem considered in the previous section has led to the complex linear system

$$C\underline{w} + \underline{b} = \underline{0} \tag{3-1}$$

where C is an N x N conjugate-symmetric matrix, \underline{b} is a complex forcing N-vector and \underline{w} is the complex adaptive weight N-vector to be determined. Recall that (3-1) simply states the necessary condition that $P_C(\underline{w})$ attain a minimum at some value of \underline{w} . More specifically, (3-1) requires that the complex gradient of $P_C(\underline{w})$ with respect to \underline{w} be identically equal to zero at a minimum point, \underline{w} .

The desired complex adaptive weight N-vector, $\underline{\mathbf{w}}$, may be determined by means of the CD and CG methods to be derived. Central to this development are the algebraic properties of $\underline{\mathbf{b}}$ and C in (3-1). To start with, it is important to note a fundamental property of the complex N-vector $\underline{\mathbf{b}}$ based on the geometrical significance of (3-1). Letting $\mathbf{C}^{\mathbf{N}}$ denote the complete complex N-space, define the eigenspace of matrix $\underline{\mathbf{C}}$ by

$$c^{\mathbb{R}} \equiv \{ \underline{\mathbf{v}} \in c^{\mathbb{N}} : c_{\underline{\mathbf{w}}} = \underline{\mathbf{v}}, \ \forall \, \underline{\mathbf{w}} \in c^{\mathbb{N}} \}$$
 (3-2)

Note that C^R is a subspace of C^N generated by C upon operating on all members of C^N . The superscript R in C^R refers to the fact that it may be spanned by a linear combination of no less than R independent complex N-vectors. In fact, R = rank C < N. In view of (3-2), the complement space, $\overline{C^R} = C^N - C^R$, is the null-space of C. Clearly, $C_N = 0$ if $N \in \overline{C^R}$. Since (3-1) is satisfied exactly, it follows that $N \in \overline{C^R} = \emptyset$; that is $N \in \overline{C^R}$ is entirely contained in the eigenspace of C. This property of $N \in \overline{C^R}$ is pertinent to the mathematical development that follows.

The special properties of matrix C are also crucial in the subsequent discussion. Note that C is a Hermitian matrix with the conjugate-symmetric property

$$C = C^{*T}$$
 (3-3)

An important consequence of this property is embodied in the following theorem.

Theorem 3-1. [Eigenvalue Property of a Hermitian Matrix C]

The eigenvalues of an N \times N complex Hermitian matrix C are non-negative real.

<u>Proof:</u> Let $e \in \mathbb{C}^R$ be a nontrivial eigenvalue of C with a nonzero eigenvalue λ . Then, by definition,

$$Ce = \lambda e \tag{3-4}$$

where e is understood to be normalized to a unit Euclidean length; i.e.,

$$\|\underline{e}\|^2 = (\underline{e}, \underline{e}) = \underline{e}^{*T}\underline{e} = 1$$
 (3-5)

Then, it follows from (3-4) and (3-5) that

$$(\underline{e}, C\underline{e}) = \underline{e}^{\dagger T} C\underline{e}$$

$$= \underline{e}^{\dagger T} \lambda \underline{e}$$

$$= \lambda \underline{e}^{\dagger T} \underline{e}$$

$$= \lambda \qquad (3-5)$$

whence, (3-3) implies that

$$\lambda^{*} = (\underline{e}, C\underline{e})^{*}$$

$$= (\underline{e}^{*T}C\underline{e})^{*}$$

$$= e^{T}C^{*}\underline{e}^{*}$$

$$= (C^{*T}\underline{e})^{T}\underline{e}^{*}$$

$$= (C\underline{e})^{T}\underline{e}^{*}$$

$$= \lambda \underline{e}^{T}\underline{e}^{*}$$

$$= \lambda \underline{e}^{*T}\underline{e}$$

$$= \lambda$$

$$= (3-7)$$

Hence, the nontrivial eigenvalues of C are positive real. If $\underline{e} \in \overline{C^R}$, it follows by (3-2) and (3-4) that $\lambda = 0$. Therefore, the eigenvalues of C are non-negative real.

An important implication of the above result is the <u>non-negative</u> definite property of C in the following corollary,

Corollary 3-2. [Non-negative Definite Property of a Hermitian Matrix C] Let C be any N x N Hermitian matrix. Then for any $\underline{w} \in \mathcal{C}^{\mathbb{N}}$,

$$(\underline{\mathbf{w}}, \ \underline{\mathbf{C}}\underline{\mathbf{w}}) = \mathbf{a} \ge 0 \tag{3-8}$$

where a is real.

Proof: Let

$$\underline{w} = \sum_{i=1}^{N} d_{i}\underline{e}^{i}$$

$$= \sum_{i=1}^{R} d_{i} \underline{e}^{i} + \sum_{i=R+1}^{N} d_{i} \underline{e}^{i}$$

$$= \underline{w}^{R} + \underline{w}^{\overline{R}}$$
(3-9)

where $\underline{w}^R \in C^R$ and $\underline{w}^R \in \overline{C^R}$. Also, $\left\{ \underline{e}^i \right\}_{i=1}^N$ is a complete orthonormal basis of complex N-vectors in C^N , the first R of which are the nontrivial eigenvectors of C contained in C^R while the remaining N-R are contained in $\overline{C^R}$. Note that (3-19) may be written as

$$\underline{\mathbf{w}} = \mathbf{E}\mathbf{D} \tag{3-10}$$

where E is an N x N complex matrix whose columns are the eigenvectors $\underbrace{\{\underline{e}^i\}}_{i=1}^N$ and D is a diagonal matrix of the corresponding coefficients $\{\underline{d}_i\}_{i=1}^N$. Recalling that C may be written as the similarity transformation

$$C = E \Lambda E^{*T}$$
 (3-11)

where Λ is the diagonal matrix of eigenvalues of C, we see that by the unitary property † of E,

$$(\underline{w}, C\underline{w}) = \underline{w}^{*T} \underline{C}\underline{w}$$

$$= \underline{D}^{*} \underline{E}^{*T} \underline{E} \underline{\Lambda} \underline{E}^{*E} \underline{D}$$

$$= \underline{D}^{*} \underline{\Lambda} \underline{D}$$

$$= \sum_{i=1}^{R} \lambda_{i} |\underline{d}_{i}|^{2}$$

$$= (\underline{w}^{R}, \underline{C}\underline{w}^{R})$$

$$\geq 0 \qquad (3-12)$$

clearly, a non-negative real quantity. In particular, note that when $\underline{w} = \underline{w}R$, (3-12) is identically equal to zero.

 $^{^{\}dagger}$ An N x N matrix E is unitary if $E^{-1} = E^{*T}$.

Another property of C that pertains to the discussion to follow is included in the following lemma.

Lemma 3-3. [Mutual Conjugacy of Two Vectors with Respect to a Hermitian Matrix C]

Let C be an N x N complex Hermitian matrix. Then, for some $\underline{u},\,\underline{v}\in \,C^N$,

$$(\underline{\mathbf{u}}, \ \mathbf{C}\underline{\mathbf{v}}) = \mathbf{0} \tag{3-13}$$

if an only if

$$(\underline{\mathbf{v}}, \ C\underline{\mathbf{u}}) = 0 \tag{3-14}$$

By (3-13), \underline{u} is orthogonal to \underline{cv} or C-conjugate to \underline{v} . Similarly (3-14) states that \underline{v} is C-conjugate to \underline{u} . When both (3-13) and (3-14) hold, \underline{u} and \underline{v} are said to be mutally conjugate with respect to C, or <u>mutually C-conjugate</u>.

<u>Proof:</u> Assume that (3-13) holds for some \underline{u} , $\underline{v} \in C^N$. We wish to show that (3-14) holds by implication. Accordingly,

$$0 = (\underline{u}, C\underline{v})$$

$$= (\underline{u}, C\underline{v})^{*T}$$

$$= (\underline{u}^{*T}C\underline{v})^{*T}$$

$$= \underline{v}^{*T}C^{*T}\underline{u}$$

$$= (\underline{v}, C\underline{u}) \qquad (3-15)$$

as desired. The reverse implication is the identical argument in reverse.

3.1.1 Derivation of the CD Method

Consider the complex linear system (3-1). Let \underline{w}^0 be an arbitrarily chosen initial estimate of its general solution, $\underline{\tilde{w}}$, defined by (2-23). Corresponding to this estimate, define the initial residual vector

$$\underline{\mathbf{r}}^0 = \underline{\mathbf{C}}\underline{\mathbf{w}}^0 + \underline{\mathbf{b}} \tag{3-16}$$

which, as described previously, represents the complex gradient of the combined power function, $P_C(\underline{w})$, with respect to \underline{w} , evaluated at \underline{w}^0 . Then, assuming that rank $C = R \leq \overline{N}$, there exists a set of Q linearly independent N-vectors

$$\left\{ \underline{p}^{k} \right\}_{k=0}^{Q-1} \in C^{N} \tag{3-17}$$

where Q \leq R, such that, a general solution to (3-1) may be expressed as the linear combination

$$\underline{\tilde{w}} = \underline{w}^0 - \sum_{k=0}^{Q-1} \alpha_k \underline{p}^k$$
 (3-18)

where $\{\alpha_k\}_{k=0}^{Q-1}$ are expansion coefficients to be determined. Since the residual vector, $\tilde{\underline{r}}$, corresponding to solution $\frac{\tilde{w}}{w}$ happens to be identically equal to zero, it follows from (3-16) and (3-18) that

$$\underline{\mathbf{r}}^0 = \sum_{k=0}^{Q-1} \alpha_k C \underline{\mathbf{p}}^k \tag{3-19}$$

If a linearly independent set of vectors $\{p^k\}_{k=0}^{Q-1}$ could be constructed such that any two different vectors could be mutually C-conjugate, then the computation of the expansion coefficients would follow readily. In fact, if

$$(\underline{p}^{i}, c\underline{p}^{j}) = 0$$

 $i, j \in [0, Q-1]; i \neq j$ (3-20)

then, in view of (3-19)

$$\alpha_{k} = \frac{(\underline{p}^{k}, \underline{r}^{k})}{(\underline{p}^{k}, \underline{c}\underline{p}^{k})}$$

$$\forall k \in [0, Q-1]$$
(3-21)

provided that $(p^k, Cp^k) \neq 0$, or, more precisely, $Cp^k \neq 0$. This clearly indicates that the vectors $\{p^k\}_{k=0}^{\infty}$ must intersect the eigenspace of C to be admissible. The appropriateness of the C-conjugacy condition (3-20) is proved in the lemma that follows.

Lemma 3-4. [Consistency of Linear Independence and Mutual C-Conjugacy of Vectors $\{p^k\}_{k=0}^{Q-1}$]

Assume that vectors $\{p^k\}_{k=0}^{Q-1}$ are mutually C-conjugate in accordance to (3-20). This choice is consistent with the linear independence assumption of these vectors.

<u>Proof:</u> Let $\{p^k\}_{k=0}^{Q-1}$ be a set of linearly independent vectors. Then, by definition,

$$\sum_{k=0}^{Q-1} \alpha_k \underline{p}^k = \underline{0} \tag{3-22}$$

if and only if $\alpha_k = 0$, $\forall k \in [0, Q-1]$. Assuming that

$$c_{\underline{p}}^{j} \neq 0$$
 (3-23)

it follows by (3-19) and (3-21) that

$$0 = \left(\sum_{k=0}^{Q-1} \alpha_k \underline{p}^k, c_{\underline{p}}^j\right)$$
$$= \alpha_j(\underline{p}^j, c_{\underline{p}}^j) \qquad (3-24)$$

which implies that $\alpha_j = 0$, since, by Corollary 3-2, $(\underline{p}^j, C\underline{p}^j) \neq 0$ $\forall j \in [0, Q-1]$. Hence, linear independence of the set of Q vectors $\{p^k\}_{k=1}^{Q-1}$ is consistent with their mutual C-conjugacy.

The general solution (3-18) may be viewed as a finite sequence of estimates $\left\{ \underline{w^i} \right\}$ $\stackrel{0-1}{i=0}$ where

$$\underline{w}^{i} = \underline{w}^{0} - \sum_{k=0}^{i-1} \alpha_{k} \underline{p}^{k}$$
 (3-25)

written, alternatively, as the recursion relation

$$\underline{\mathbf{w}}^{\mathbf{i}+1} = \underline{\mathbf{w}}^{\mathbf{i}} - \alpha_{\mathbf{i}}\underline{\mathbf{p}}^{\mathbf{i}} \tag{3-26}$$

where i = 0, 1, ..., Q-1. Clearly, solution (3-18) is simply

$$\underline{\widetilde{w}} = \underline{w}^{Q-1} \tag{3-27}$$

the last iterate of (3-26). Upon substituting (3-26) into (3-1), we get a similar recursion relation for the set of corresponding residual vectors $\{ri\}_{i=1}^{Q-1}$; i.e.,

$$\underline{r}^{i+1} = \underline{r}^{i} - \alpha_{i} c \underline{p}^{i}$$
 (3-28)

where i = 0, 1, ..., Q-1. The residual of the solution (3-27), clearly the last iterate of (3-28), is identically equal to zero as mentioned previously; that is,

$$\underline{\tilde{\mathbf{r}}} = \underline{\mathbf{r}}^{Q-1} = \underline{\mathbf{0}} \tag{3-29}$$

which is consistent with expression (3-19). In view of (3-21), (3-26) and (3-28), we have proved one form of the general CD method included in the following theorem.

Theorem 3-5. [Standard Form of the CD Method]

Consider the linear system

$$Cw + \underline{b} = \underline{0} \tag{3-30}$$

where C is an N x N complex Hermitian matrix of rank R, \underline{b} is a complex N-vector contained in C^R , the eigenspace of C, and \underline{w} is the unknown complex N-vector to be determined. Let

$$\left\{ \underbrace{\mathbf{p}}^{\mathbf{i}} \right\}_{\mathbf{i}=0}^{\mathbf{Q}-\mathbf{1}} \tag{3-31}$$

be a set of Q, Q \leq R \leq N , linearly independent complex N-vectors having the properties of

(1) Nonzero intersection with eigenspace C^R ; i.e.,

$$\begin{array}{c}
\mathbf{p}^{\mathbf{i}} \cap \mathbf{C}^{\mathbf{R}} \neq \emptyset \\
\mathbf{v} \ \mathbf{i} \in [0, \ Q-1]
\end{array}$$
(3-32)

(2) Spanning the eigenspace C^R via a linear combination; i.e.,

$$C^{R} \in \left\{ \underline{v} \in C^{N} : \underline{v} = \sum_{i=0}^{Q-1} a_{i}\underline{p}^{i} ; v a_{i} \in C^{1}, i \in [0, Q-1] \right\}$$
 (3-33)

where C¹ is the space of complex scalars.

(3) Mutual C-conjugacy property; i.e.,

$$(\underline{p}^{i}, c\underline{p}^{j}) = 0$$

 $\forall i, j \in [0, Q-1]; i \neq j$
(3-34)

Then, a general solution to (3-30) is the last iterate, \underline{w}^{Q-1} , of the Q-step iterative procedure that begins with an initial solution estimate \underline{w}^0 and corresponding residual vector $\underline{r}^0 = \underline{C}\underline{w}^0 + \underline{b}$ and repeats relations

$$\alpha_{i} = \frac{(\underline{p}^{i}, \underline{r}^{0})}{(\underline{p}^{i}, \underline{c}\underline{p}^{i})}$$
(3-35.1)

$$\underline{w}^{i+1} = \underline{w}^{i} - \alpha_{i}\underline{p}^{i}$$
 (3-35.2)

$$\underline{\mathbf{r}}^{\mathbf{i}+1} = \underline{\mathbf{r}}^{\mathbf{i}} - \alpha_{\mathbf{i}} c_{\underline{\mathbf{p}}}^{\mathbf{i}}$$
 (3-35.3)

for $i=0,1,\ldots,Q-1$. This procedure will be referred to as the standard form of the conjugate directions (CD) method, where conjugate directions refers to the C-conjugate set of vectors $\{\underline{p}^1\}_{i=0}^{Q-1}$

<u>Proof:</u> The hypotheses and the standard CD method stated by this theorem follows from preceding discussion starting with Section 3.1.

Although the standard CD method is strictly correct as stated in (3-35), attempts to minimize roundoff error in actual computation has led to a slight reformulation of the algorithm [2]. The basis for the alternate CD algorithm is the following lemma.

Lemma 3-6. [Special Properties of $(\underline{p}^i, \underline{r}^j)$ in CD Method]

In the standard CD method defined by Theorem 3-5, the inner product $(\underline{p}^i, \underline{r}^j)$ has the following properties:

$$(\underline{p}^{i}, \underline{r}^{j}) = (\underline{p}^{i}, \underline{r}^{0})$$

 $\forall i \geq j ; i, j \in [0, Q-1]$
(3-36)

and

$$(\underline{p}^{i}, \underline{r}^{j}) = 0$$

 $\forall i < j ; i \in [0, Q-1], j \in [1, Q-1]$
(3-37)

<u>Proof:</u> By the C-conjugacy property (3-34) and recursion (3-35.3), we see that

$$(p^{i}, \underline{r}^{i}) = (p^{i}, \underline{r}^{i-1}) - \alpha_{i}(\underline{p^{i}}, \underline{cp^{i-1}})^{0}$$

$$= (p^{i}, \underline{r}^{i-2}) - \alpha_{i-1}(\underline{p^{i}}, \underline{cp^{i-2}})^{0}$$

$$\vdots$$

$$= (p^{i}, \underline{r}^{0})$$
 (3-38)

 $\forall i \geq j$; i, $j \in [0, Q-1]$. This is precisely (3-36). On the other hand, using the additional expression for expansion coefficient (3-35.1) and incorporating (3-38), we see that, for i < j,

$$(\underline{p}^{i}, \underline{r}^{j}) = (\underline{p}^{i}, \underline{r}^{j-1}) - \alpha_{j-1}(\underline{p}^{i} - c\underline{p}^{j-1})$$

$$\vdots$$

$$= (\underline{p}^{i}, \underline{r}^{i}) - \alpha_{i}(\underline{p}^{i}, c\underline{p}^{i})$$

$$= 0 \qquad (3-39)$$

 $\forall i < j ; i \in [0, Q-1], j \in [1, Q-1].$ This completes the proof.

The alternate form of the CD method may now be stated in the following theorem.

Theorem 3-7. [Alternate Form of the CD Method]

Given all the hypotheses of Theorem 3-5, a general solution to (3-30) is the last iterate, \underline{w}^{Q-1} , of the Q-step iterative procedure that begins with an aribitrary initial solution estimate, \underline{w}^0 , and the corresponding residual vector, $\underline{r}^0 = \underline{C}\underline{w}^0 + \underline{b}$, and repeats relations

$$\alpha_{i} = \frac{(p^{i}, r^{i})}{(p^{i}, cp^{i})}$$
 (3-40.1)

$$\underline{\mathbf{w}}^{\mathbf{i}+1} = \underline{\mathbf{w}}^{\mathbf{i}} - \alpha_{\mathbf{i}} \underline{\mathbf{p}}^{\mathbf{i}} \tag{3-40.2}$$

$$\underline{r}^{i+1} = \underline{r}^{i} - \alpha_{i} C \underline{p}^{i} \tag{3-40.3}$$

for i = 0, 1, ..., Q-1. This procedure will be referred to as the <u>alternate</u> form of the conjugate directions (CD) method.

Proof: Result (3-40) follows from Theorem 3-6 and Lemma 3-7.

The description of the CD method is not complete without a means for constructing the set of linearly independent C-conjugate vectors, $\left\{ \begin{array}{c} p^1 \\ q^{-1} \end{array}\right\}$. One possible construction involves the use of a complete orthogonal basis of vectors, $\left\{ \begin{array}{c} q^1 \\ q^{-1} \end{array}\right\}$, which can span the complex N-space, C^N , via a linear combination in the sense of (3-33). Subsequently, using a procedure similar to the Gram-Schmidt process, it is possible to generate a set of mutually C-conjugate vectors $\left\{ \begin{array}{c} p^1 \\ q^{-1} \end{array}\right\}$, as desired. This construction scheme is presented in the following lemma.

<u>Lemma 3-8.</u> [Construction of C-Conjugate set of N-vectors $\{\underline{p}^i\}_{i=0}^{Q-1}$ from a Complete Orthogonal Set $\{\underline{q}^i\}_{i=0}^{N-1}$]

Let $\{q^i\}_{i=0}^{N-1}$ be a complete orthogonal basis of C^N ; i.e.,

$$C^{N} = \left\{ \underline{v} : \underline{v} = \sum_{i=0}^{N-1} a_{i} \underline{q}_{i} ; \forall a_{i} \in C^{1}, i \in [0,N-1] \right\}$$
 (3-41)

Then, a set of Q linearly independent C-conjugate vectors $\{p^i\}_{i=0}^{Q-1}$ may be defined as follows. The first vector is arbitrarily defined by

$$p^0 = q^{k_0}$$
 (3-42)

where $k_0 = \min[0, N-1] \ni Cp^0 \neq \underline{0}$. The general such vector is given by

$$p^{i} = q^{k_{i}} + \sum_{j=0}^{i-1} \beta_{i,j} p^{j}$$
 (3-43)

where

$$\beta_{i,j} = \frac{(q^{i_1}, cp^{j})}{(p^{j}, cp^{j})}$$
 (3-44)

and $\{k_i\}$ is a subsequence of indices in the range [0, N-1] while i and j range over [0, Q-1] and [0, Q-2], respectively, with i > j. Furthermore, $Q \le R = \text{rank } C$.

<u>Proof</u>: Following the Gram-Schmidt (GS)[†] procedure, the first of the C-conjugate vectors, \underline{p}^0 , is defined by

$$\mathbf{p}^{0} = \mathbf{q}^{\mathbf{k}_{0}} \tag{3-45}$$

[†]In the standard GS procedure \underline{p}^1 is constructed to be orthogonal to \underline{p}^0 by removing from q^{k_1} its orthogonal projection, $\beta_{1,0}\,\underline{p}^0$, onto \underline{p}^0 . In contrast, the GS procedure appropriate for the CD method requires that \underline{p}^1 and \underline{p}^0 be mutually C-conjugate.

where $k_0 = \min[0, N-1] \ni \underline{q}^0 \cap C^R \neq \emptyset$, or $C\underline{q}^{k_0} = C\underline{p}^0 \neq \underline{0}$. The next C-orthogonal vector is given by

$$\underline{p}^{1} = \underline{q}^{k_{1}} + \beta_{1,0} \underline{p}^{0} \tag{3-46}$$

where $k_1 = \min[k_0+1, N-1] \ni \underline{q}^{k_1} \cap C^R \neq \emptyset$, or $\underline{Cp}^1 \neq \underline{0}$. The GS coefficient $\beta_{1,0}$ is determined by invoking the desired C-conjugacy between \underline{p}^1 and \underline{p}^0

$$0 = (\underline{p}^{1}, c\underline{p}^{0})$$

$$= (\underline{q}^{k_{1}} + \beta_{1,0}(\underline{p}^{0}, c\underline{p}^{0}))$$

$$= (\underline{q}^{k_{1}}, c\underline{p}^{0}) + \beta_{1,0}(\underline{p}^{0}, c\underline{p}^{0})$$
(3-47)

yielding

$$\beta_{1,0} = -\frac{(\underline{q}^{k_1}, \underline{c}\underline{p}^0)}{(\underline{p}^0, \underline{c}\underline{p}^0)}$$
 (3-48)

which is well-defined, since $(\underline{p}^0, C\underline{p}^0) > 0$ by Corollary 3-2. Proceeding accordingly, the general C-conjugate vector is given by the familiar telescoping series

$$\underline{p}^{i} = \underline{q}^{k_{i}} + \sum_{j=0}^{i-1} \beta_{i,j} \underline{p}^{j}$$
 (3-49)

where $k_i = \min\{k_{i-1}+1, N-1\} \ni \underline{q}^{k_i} \cap C^R \neq \emptyset$, or $C\underline{p}^i \neq \underline{0}$. By mutual C-conjugacy of \underline{p}^i and the set of previously defined vectors $\{\underline{p}^j\}_{j=0}^{i-1}$, we can determine the GS coefficients $\{\beta_{i,j}\}_{j=0}^{i-1}$. In fact, for $j \in [0, i-1]$, (3-48) implies that

$$0 = (\underline{p}^{i}, c\underline{p}^{j})$$

$$= (\underline{q}^{k_{i}} + \beta_{i,j}\underline{p}^{j}, c\underline{p}^{j})$$

$$= (\underline{q}^{k_{i}}, c\underline{p}^{j}) + \beta_{i,j}(\underline{p}^{j}, c\underline{p}^{j})$$
(3-50)

yielding

$$\beta_{i,j} = -\frac{(q^{k_i}, c_p^j)}{(p^j, c_p^j)}$$
 (3-51)

where $k \in [0, N-1] \ni q^{k_i} \cap C^R \neq \emptyset$, $i \in [0, Q-1]$, $j \in [0, Q-2]$ and i > j. Note that $Q \leq R = \operatorname{rank} C$, since it takes no more than R linearly independent vectors to span C^R .

Variations on the basic construction approach described above are possible. However, the most interesting such construction is the built-in GS procedure of the CG method developed next.

3.1.2 Derivation of the CG Method

The CG method is a special case of the CD method in which the basis vectors are the iteratively generated gradients $\{r^i\}$ Q-1 which are used to construct corresponding C-conjugate search vectors i=1 $\{p^i\}$ $\{q^i\}$ via a procedure similar to that of Lemma 3-8. It turns out that this particular choice of basis vectors leads to a relatively simple expression for the general C-conjugate vector. In contrast to the telescoping complexity (3-43) in the CD method, the general C-conjugate vector in the CG method is given by a first-order recursion involving the current gradient vector and the previous C-conjugate vector as indicated in (2-48.3). This constitutes the major advantage of the CG method over the general CD method which becomes especially significant with increasing system dimensionality, N.

The rigorous derivation of the CG method follows logically from the general CD theory already developed, as presented in the following theorem.

Theorem 3-9. [Conventional Form of the CG Method]

Consider the linear system

$$C\underline{w} + \underline{b} = \underline{0} \tag{3-52}$$

where C is an N x N complex Hermitian matrix of rank R, \underline{b} is a complex N-vector contained in C^R , the eigenspace of C, and \underline{w} is the unknown complex N-vector to be determined. Then, a general solution to (3-52) is the last iterate, \underline{w}^{Q-1} , of a Q-step iterative procedure that begins with an initial solution estimate, \underline{w}^0 , and a corresponding residual, $\underline{r}^0 = C\underline{w}^0 + \underline{b}$, and repeats relations

$$\alpha_{i} = \frac{\|\underline{r}^{i}\|^{2}}{(\underline{p}^{i}, c\underline{p}^{i})}$$
 (3-53.1)

$$\underline{\mathbf{w}}^{\mathbf{i}+1} = \underline{\mathbf{w}}^{\mathbf{i}} - \alpha_{\mathbf{i}}\underline{\mathbf{p}}^{\mathbf{i}} \tag{3-53.2}$$

$$\underline{r}^{i+1} = \underline{r}^{i} - \alpha_{i} c \underline{p}^{i}$$
 (3-53.2)

$$\beta_{i} = \frac{\|\underline{r}^{i+1}\|^{2}}{\|r^{i}\|^{2}}$$
 (3-53.4)

for i = 0, 1, ..., Q-1. This procedure will be referred to as the <u>conventional</u> form of the conjugate gradients (CG) method, where conjugate gradients refers to the orthogonal set of gradient basis vectors, $\{r^i\}$ $\{q-1\}$, generated.

<u>Proof</u>: Let \underline{w}^0 be an arbitrarily chosen initial estimate. If the corresponding residual or gradient vector $\underline{r} = \underline{0}$, Q = 1 and the theorem holds trivially. Assume that $\underline{r}^0 \neq \underline{0}$. Then, let the initial C-conjugate vector be defined by

$$\underline{p}^0 = \underline{r}^0 \tag{3-54}$$

By Theorem 3-7, relations (3-40.1) and (3-40.3), it follows that

$$\alpha_0 = \frac{\|\underline{r}^0\|^2}{(\underline{p}^0, \underline{cp}^0)}$$
 (3-55.1)

$$\underline{r}^1 = \underline{r}^0 - \alpha_0 C \underline{p}^0 \tag{3-55.2}$$

With \underline{r}^1 at hand, define the second C-conjugate vector

$$\underline{p}^{1} = \underline{r}^{1} + \beta_{1,0} \underline{p}^{0} \tag{3-56}$$

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Then, by (3-54) and Lemma 3-6,

$$0 = (\underline{p}^{0},\underline{r}^{1})$$

$$= (\underline{r}^{0},\underline{r}^{1})$$
 (3-57)

implying that the first two gradient vectors, \underline{r}^0 and \underline{r}^1 , are mutually orthogonal. This qualifies then as basic vectors, as desired.

For \underline{p}^1 to be an admissible C-conjugate vector, it must be C-orthogonal to \underline{p}^0 . In fact, if $\underline{r}^1 \neq \underline{0}$, there exists a coefficient $\beta_{1,0}$ such that the C-conjugacy holds nontrivially. Invoking the C-conjugacy condition, and using (3-54) - (3-57), we have

$$0 = (\underline{p}^{1}, \underline{c}\underline{p}^{0})$$

$$= \frac{1}{\alpha_{0}} (\underline{r}^{1} + \beta_{1,0} \underline{p}^{0}, \underline{r}^{0} - \underline{r}^{1})$$

$$= (\underline{r}^{1}, \underline{r}^{0})^{0} - ||\underline{r}^{1}||^{2} + \beta_{1,0} ||\underline{r}^{0}||^{2} - (\underline{p}^{0}, \underline{r}^{1})^{0}$$
(3-58)

whence.

$$\beta_{1,0} = \frac{\|\underline{r}^1\|^2}{\|\underline{r}^0\|^2} \tag{3-59}$$

which is well-defined, since $\underline{r}^0 \neq \underline{0}$.

In view of (3-56) and (3-57),

$$(\underline{p}^{1},\underline{r}^{1}) = (\underline{r}^{1} + \beta_{1,0}\underline{p}^{0},\underline{r}^{1})$$

$$= ||\underline{r}^{1}||^{2}$$
(3-60)

so that, by Theorem 3-7,

$$\alpha_1 = \frac{\|\underline{r}^1\|^2}{(\underline{p}^1, \underline{c}\underline{p}^1)}$$
 (3-61.1)

$$\underline{\mathbf{r}}^2 = \underline{\mathbf{r}}^1 - \alpha_1 C \underline{\mathbf{p}}^1 \tag{3-61.2}$$

Now, define the third C-conjugate vector by

$$\underline{p}^2 = \underline{r}^2 + \beta_{2,0} \underline{p}^0 + \beta_{2,1} \underline{p}^1 \tag{3-62}$$

Before proceeding with the actual determination of constants $\beta_{2,0}$ and $\beta_{2,1}$, it is important to establish the orthogonality of \underline{r}^2 to \underline{r}^0 and \underline{r}^1 . By (3-54), (3-56) and Lemma 3-6,

$$0 = (\underline{p}^{0}, \underline{r}^{2})$$

$$= (\underline{r}^{0}, \underline{r}^{2})$$

$$0 = (\underline{p}^{1}, \underline{r}^{2})$$

$$= (\underline{r}^{1} + \beta_{1,0} \underline{p}^{0}, \underline{r}^{2})$$

$$= (\underline{r}^{1}, \underline{r}^{2}) + \beta_{1,0} \underline{r}^{0}, \underline{r}^{2}$$

$$(3-63.2)$$

which, combined with (3-57), may be summarized as

$$(\underline{r}^{i},\underline{r}^{j}) = 0$$

 $\forall i,j [0,2]; i \neq j$ (3-64)

the desired orthogonality property of the first three gradient vectors.

It is now possible to specify (3-61). Invoking the C-conjugacy condition, and using (3-54), (3-55.2), (3-58) and (3-64) we get

$$0 = (\underline{p}^{2}, C\underline{p}^{0})$$

$$= (\underline{r}^{2} + \beta_{2,0} \underline{p}^{0} + \beta_{2,1} \underline{p}^{1}, C\underline{p}^{0})$$

$$= (\underline{r}^{2} + \beta_{2,0} \underline{p}^{0}, \underline{r}^{0} - \underline{r}^{1})$$

$$= \beta_{2,0} ||\underline{r}^{0}||^{2}$$
(3-65)

implying that

$$\beta_{2,0} = 0 \tag{3-66}$$

Similarly, using (3-60), (3-66) and (3-61.2),

$$0 = (\underline{p}^{2}, \underline{c}\underline{p}^{1})$$

$$= (\underline{r}^{2} + \beta_{2,1}\underline{p}^{2}, \underline{c}\underline{p}^{2})$$

$$= (\underline{r}^{2} + \beta_{2,1}\underline{p}^{1}, \underline{r}^{2} - \underline{r}^{1})$$

$$= ||\underline{r}^{2}||^{2} + \beta_{2,1}(\underline{p}^{1}, \underline{r}^{1})$$

$$= ||\underline{r}^{2}||^{2} + \beta_{2,1}||\underline{r}^{1}||^{2}$$
(3-67)

which leads to

$$\beta_{2,1} = \frac{\|\underline{r}^2\|^2}{\|\underline{r}^1\|^2}$$
 (3-68)

From (3-66) and (3-68) we can conclude that (3-62) reduces to an expression for \underline{p}^2 dependent on \underline{r}^2 and \underline{p}^1 but not on \underline{p}^0 . We are thus tempted to conclude, that (3-53.5) holds in general. To prove this assumption, we use induction. Assume that, in the k-th iteration, we have

$$\underline{p}^{k} = \underline{r}^{k} + \beta_{k}\underline{p}^{k} \tag{3-69.1}$$

$$(\underline{r}^{i},\underline{r}^{j}) = 0$$
, $\forall i,j \in [0,k]$; $i \neq j$ (3-69.2)

We wish to show that (3-69) holds for the (k+1)st iteration. Noting that

$$\underline{\mathbf{r}}^{\ell+1} = \underline{\mathbf{r}}^{\ell} - \alpha_{\ell} \mathbf{C} \underline{\mathbf{p}}^{\ell}$$

$$\forall \ \ell \in [0,k]$$
(3-70)

by Theorem 3-7, assume that the corresponding C-conjugate vector is given by

$$\underline{p}^{k+1} = \underline{r}^{k+1} + \sum_{\ell=0}^{k} \beta_{k+1, \ell} \underline{p}^{\ell}$$
 (3-71)

We wish to show that (3-69) implies that the only nonzero coefficient in (3-71) is $\beta_{k+1,k}$ and is defined consistently with (3-53.4).

Letting $\ell \le k$, Lemma 3-6 implies that

$$0 = (\underline{p}^{\ell}, \underline{r}^{k+1})$$

$$= (\underline{r}^{\ell} + \beta_{\ell, \ell-1} \underline{p}^{\ell-1}, \underline{r}^{k+1})$$

$$= (\underline{r}^{\ell}, \underline{r}^{k+1})$$
(3-72)

which extends the orthogonality condition (3-69.2) to the (k+1)st iteration. In addition, using (3-70) and invoking C-conjugacy, we get

$$0 = (\underline{p}^{k+1}, \underline{cp}^{\ell})$$

$$= (\underline{r}^{k+1} + \sum_{\ell=0}^{k} \beta_{k+1} \underline{p}^{\ell}, \underline{cp}^{\ell})$$

$$= (\underline{r}^{k+1} + \beta_{k+1, \ell} \underline{p}^{\ell}, \underline{r}^{\ell} - \underline{r}^{\ell+1})$$

$$= - (\underline{r}^{k+1}, \underline{r}^{\ell+1}) + \beta_{k+1, \ell} (\underline{p}^{\ell}, \underline{r}^{\ell})$$

$$= - (\underline{r}^{k+1}, \underline{r}^{\ell+1}) + \beta_{k+1, \ell} ||\underline{r}^{\ell}||^{2}$$
(3-73)

which leads to

$$\beta_{k+1,\ell} = \left\{ \begin{array}{c} \frac{\|\underline{r}^{k+1}\|^2}{\|\underline{r}^k\|^2} \; ; \quad \ell = k \\ 0 \; ; \quad \ell \le k \end{array} \right\} \equiv \beta_k \tag{3-74}$$

In view of (3-69) and (3-74), (3-69) has been extended to the (k+1)st iteration and thus holds in general. As a consequence, the CG procedure (3-53) is valid for i = 0, 1, ..., Q-1 where Q is the iteration number for which $\underline{r}Q = 0$. This completes the proof.

As in the case of the general CD method, the CG method has standard and alternate forms as stated in the following two theorems.

Theorem 3-10. [Standard Form of the CG Method]

Given all the hypotheses of Theorem 3-9, a general solution to (3-52) is the last iterate, $\underline{w}Q^{-1}$, of the Q-step iterative procedure that begins with an arbitrary initial solution estimate, \underline{w}^0 , and the corresponding C-conjugate and residual vectors $\underline{p}^0 = \underline{r}^0 = \underline{c}\underline{w}^0 + \underline{b}$ and repeats relations

$$\alpha_{i} = \frac{(p^{i}, r^{0})}{(p^{i}, cp^{i})}$$
 (3-75.1)

$$\underline{\mathbf{w}}^{\mathbf{i}+\mathbf{1}} = \underline{\mathbf{w}}^{\mathbf{i}} - \alpha_{\mathbf{i}} \mathbf{p}^{\mathbf{i}} \tag{3-75.2}$$

$$\underline{r}^{i+1} = \underline{r}^{i} - \alpha_{i} C \underline{p}^{i}$$
 (3-75.3)

$$\beta_{i} = \frac{\left\| \underline{r}^{i+1} \right\|^{2}}{\left\| \underline{r}^{i} \right\|^{2}}$$
 (3-75.4)

$$\underline{p}^{i+1} = \underline{r}^{i+1} + \beta_{i}\underline{p}^{i}$$
 (3-75.5)

for i = 0, 1, ..., Q-1. This procedure is referred to as the standard form of the conjugate gradients (CG) method.

Proof: Result (3-75) follows from Theorems 3-5 and 3-9.

Theorem 3-11. [Alternate Form of the CG Method]

Given all the hypotheses of Theorem 3-9, a general solution to (3-52) is the last iterate, \underline{w}^{Q-1} , of the Q-step iterative procedure that begins with an arbitrary initial solution estimate, \underline{w}^0 , and the corresponding C-conjugate and residual vectors $\underline{p}^0 = \underline{r}^0 = \underline{c}\underline{w}^0 + \underline{b}$ and repeats relations

$$\alpha_{i} = \frac{(\underline{p}^{i},\underline{r}^{i})}{(\underline{p}^{i},\underline{c}\underline{p}^{i})}$$
(3-76.1)

$$\underline{\mathbf{w}}^{\mathbf{i}+1} = \underline{\mathbf{w}}^{\mathbf{i}} - \alpha_{\mathbf{i}} \underline{\mathbf{p}}^{\mathbf{i}}$$
 (3-76.2)

$$\underline{r}^{i+1} = \underline{r}^{i} - \alpha_{i} c \underline{p}^{i} \tag{3-76.3}$$

$$\beta_{i} = \frac{\|\underline{r}^{i+1}\|^{2}}{\|\underline{r}^{i}\|^{2}}$$
 (3-76.4)

$$\underline{r}^{i+1} = \underline{r}^{i+1} + \beta_{i}\underline{p}^{i}$$
(3-76.5)

for i = 0, 1, ..., Q-1. This procedure is referred to as the <u>alternate form</u> of the conjugate gradients (CG) method.

Proof: Result (3-76) follows from Theorems 3-7 and 3-9.

3.2 Properties of the CG Method

The CG method has a number of special properties, some of which are discussed below. As in the case of the general CD method, the CG method may be designed to yield a minimum-norm solution as well as an intinsic inverse. Its numerically-efficient, flexible and stable structure characterizes its overall numerical robustness.

3.2.1 Minimum-Norm Solution

The condition under which the CG method yields the unique minimumnorm solution to (3-52) is stated in the following theorem. Theorem 3-12. [Condition for Minimum-Norm CG Solution to (3-52)]

The CG method as presented in Theorems 3-9, 3-10 and 3-11 yield the unique minimum-norm solution (2-42), of system (3-52), when $\underline{w}^0 \in C^R$; that is, when the initial estimate is contained within the eigenspace of the N x N Hermitian matrix C in (3-52).

<u>Proof:</u> Note that, by (2-18), $\underline{b} \in \mathcal{C}^R$. Then, by definition (3-33), it follows that \underline{p}^0 , $\underline{r}^0 \in \mathcal{C}^R$ for any initial estimate, \underline{w}^0 . In fact, by definition (3-33), all vectors in the CG procedure are contained in \mathcal{C}^R , with the exception of \underline{w}^{i+1} . A choice $\underline{w}^0 \in \mathcal{C}^R$ guarantees that $\underline{w}^{i+1} \in \mathcal{C}^R$. Since $\underline{r}^{Q-1} = \underline{0}$ for some $Q \leq \operatorname{rank} C \leq N$, $\underline{w}^{Q-1} = \underline{\hat{w}}$, the unique minimum-norm solution (2-42).

3.2.2 Intrinsic Inverse

The CG method yields an intrinsic inverse as stated in the following theorem.

Theorem 3-13. [The CG Intrinsic Inverse of Matrix C in (3-52)]

The intrinsic inverse, CX, of matrix C in (3-52) is given by

$$c^{x} = \sum_{i=0}^{Q-1} \frac{i_{p}i^{i^{T}}}{(p^{i}, c_{p}^{i})}$$
 (3-77)

<u>Proof:</u> Let $\underline{w}^0 = \underline{0}$ in Theorem 3-10, whence $\underline{r}^0 = \underline{b}$. By Theorem 3-12, $\underline{w}Q-1 = \hat{w}$, the minimum-norm solution. Then, using (3.75.1) and (3-75.2), we see that

$$\hat{\underline{\alpha}} = -\sum_{i=0}^{Q-1} \alpha_i p^i$$

$$= -\sum_{i=0}^{Q-1} \frac{(p^{i}, \underline{b})}{(p^{i}, cp^{i})} p^{i}$$

$$= -\sum_{i=0}^{Q-1} \frac{p^{i} p^{i *^{T}}}{(p^{i}, cp^{i})} \underline{b}$$

$$= -c^{x}\underline{b}$$
(3-78)

(3-78)

where C^{X} is given by (3-77).

It should be noted that the properties of the CD intrinsic inverse discussed in Section 2.2.2.3 apply equally well to the CG intrinsic inverse.

3.2.3 Numerical Robustness

It has been shown that the CG method is a computationally efficient form of the general CD method. As a consequence, a finite-word machine computation using the CG method will yield a smaller roundoff error in the final solution. However, the most important feature of the general CD method and, hence, the CG method, is its inherent numerical stability. That is, each new weight-vector iterate, wi+1, reduces the value of the combined power metric

$$P_{c}(\underline{w}) = \|\underline{s}^{T}\underline{w} + s_{0}\|^{2}$$

$$= (\underline{w}, \langle \underline{s}, \underline{s}^{T} \rangle \underline{w}) + 2R\varrho(\underline{w}, \langle \underline{s}, s_{0} \rangle) + \|s_{0}\|^{2}$$

$$= (\underline{w}, C\underline{w}) + 2R\varrho(\underline{w}, \underline{b}) + P_{0}$$
(3-79)

where P_n is the main-port power over an M-sample batch of signal data.

Noting that $P_{c}(\underline{w})$ is a nonnegative-real quadratic function of w that represents a hyperparaboloidal surface in (2N+1)-space, its iterative reduction with each new weight estimate may be viewed geometrically as a descent process on the hypersurface along C-conjugate search directions. This descent-property which guarantees the numerical stability of the CG method is demonstrated in the following theorem.

Theorem 3-14. [Descent Property of the CG Method]

Let \underline{w} be the current estimate of some iteration in the CG procedure and consider the variation of P_C(\underline{w}) along the cord

$$\underline{\mathbf{w}}^* = \underline{\mathbf{w}} - \alpha \mathbf{p} \tag{3-80}$$

where α is a scalar factor. Then, $P_{_{C}}(\underline{w}')$ attains a unique minimum when

$$\alpha = \frac{(\underline{p},\underline{r})}{(\underline{p},\underline{C}\underline{p})} \tag{3-81.1}$$

$$= \frac{\|\mathbf{r}\|^2}{(\mathbf{p}, \mathbf{C}\mathbf{p})}$$
 (3-81.2)

It is then said that $P_c(\underline{w}')$ has been relaxed optimally along -p.

Proof: By (3-79) and (3-80)

$$P_{c}(\underline{w}') = (w', \underline{c}\underline{w}') + 2Re(\underline{w}', \underline{b}) + P_{0}$$

$$= (\underline{w} - \alpha \underline{p}, \underline{c}(\underline{w} - \alpha \underline{p})) + 2Re(\underline{w} - \alpha \underline{p}, \underline{b}) + P_{0}$$

$$= |\alpha|^{2}(\underline{p}, \underline{c}\underline{p}) - 2Re\{\alpha^{*}(\underline{p}, \underline{c}\underline{w} + \underline{b})\} + P_{c}(\underline{w})$$

$$= |\alpha|^{2}(\underline{p}, \underline{c}\underline{p}) - 2Re\{\alpha^{*}(\underline{p}, \underline{r})\} + P_{0}(\underline{w})$$

$$(3-82)$$

where α is assumed to be complex, in general. The value of α that minimizes (3-82) may be found by setting its "complex derivative" with respect to α equal to zero; i.e.,

$$0 = \frac{d}{d\alpha} P_{c}(\underline{w}^{*})$$

$$= \left(\frac{d}{d\alpha_{r}} + j\frac{d}{d\alpha_{i}}\right) P_{c}(\underline{w}^{*})$$

$$= \alpha(\underline{p}, C\underline{p}) - (\underline{p}, \underline{r})$$
(3-83)

which, for the CG case, leads to the desired result (3-81), where α is nonnegative real by Corollary 3-2. In the general CD case where (3-83) also applies, α may be complex.

Upon substituting (3-81.1) in (3-82), we get

$$P_{c}(\underline{w}') = \left| \frac{(\underline{p},\underline{r})}{(\underline{p},\underline{c}\underline{p})} \right|^{2} (\underline{p},\underline{c}\underline{p}) - 2Re \frac{(\underline{p},\underline{r})*(\underline{p},\underline{r})}{(\underline{p},\underline{c}\underline{p})} + P_{c}(\underline{w})$$

$$= P_{c}(\underline{w}) - \frac{|(\underline{p},\underline{r})|^{2}}{(\underline{p},\underline{c}\underline{p})}$$

$$\leq P_{c}(\underline{w})$$

the desired descent property.

As mentioned previously, the CG procedure will terminate at an iteration when $\|\underline{r}\| < \varepsilon \|\underline{b}\|$, where ε is a positive real scalar on the order of the precision of the sampled signal data and the machine employed. For example, if the data used is accurate to 8 bits, it is reasonable to chose $\varepsilon = 2^{-8}$, assuming the machine computation is sufficiently precise to offset any significant roundoff error buildup.

Of course, with increasing dimensionality N, it will be less and less likely that the roundoff error could be contained well enough in order that the above stopping criterion make sense. It has been shown [2] that the roundoff error buildup is worst in the standard CG method defined by (3-75). The conventional form (3-53) will reduce this error.

A further improvement may be realized in the alternate form (3-76). Finally, additional accuracy could be achieved if the GS coefficient is redefined by

$$\beta_{i} = -\frac{(\underline{r}^{i+1}, \underline{c}\underline{p}^{i})}{(\underline{p}^{i}, \underline{c}\underline{p}^{i})}$$
(3-84)

where (3-53.1) and (3-76.3) have been used to modify (3.76.4).

As N becomes larger and larger, even these measures become less effective in containing the roundoff error to a sufficiently low level. If, in fact, the roundoff error is so large that the stopping criterion is far from being satisfied, it is always possible to use the final weight estimate as an initial estimate in a second CG execution. Then, the roundoff error associated with the final estimate during the first execution could be significantly reduced during the second.

Clearly, the CG method possesses an efficient iterative structure with an inherent numerical stability and the capability of minimizing roundoff error. For these reasons, it is a numerically-robust computational procedure.

3.2.4 Cancellation Ratio Computation

In connection with the sidelobe cancellation system considered, the combined-port signal power, $P_{C}(\underline{w})$, over an M-sample batch has been given in (3-79). This expression may be rewritten as

$$P_{C}(\underline{w}) = (\underline{w}, \underline{C}\underline{w}) + (\underline{w}, \underline{b}) + (\underline{w}, \underline{b}) + P_{0}$$

$$= (\underline{w}, \underline{r}) + (\underline{w}, \underline{b}) + P_{0}$$
(3-85)

since $\underline{r} = \underline{Cw} + \underline{b}$. Note that (3-85) is completely defined by the main-port power, P_0 , the cross-correlation vector, \underline{b} , and CG variables \underline{w} and \underline{r} . As such, (3-85) is in a convenient form to compute the <u>cancellation ratio</u> as part of the BCR process. Specifically, this ratio is given by

$$CR(\underline{w}) = 10 \log_{10} \left[\frac{P_0}{P_0 + (\underline{w}, \underline{b})^* + (\underline{w}, \underline{r})} \right]$$
 (3-86)

If (3-86) were appended to the BCR process as a performance monitor, it would provide a numerically-reliable stopping criterion. In fact, by the descent property of Theorem 3-14, we should observe an increase in $CR(\underline{w})$ with each new iterate, \underline{w} . When $CR(\underline{w})$ stops decreasing appreciably or increases because of excessive roundoff error, the process may be terminated using the present or previous value of \underline{w} , as appropriate, and reinitiated as necessary.

3.3 Illustrative Examples

The overall understanding of the CG procedure may be enhanced by actually working out specific numerical examples. Below, we consider two simple examples of a two-dimensional system (3-1). The first example involves a full-rank complex Hermitian matrix C. It is solved by three different methods: inversion, CD and CG. The second example involves a real-valued singular matrix C. It is solved by regularized inversion, pseudoinversion, CD and CG. In as much as it is possible, the features of the CG method are illustrated quantitatively.

3.3.1 Full-Rank Covariance Case

Consider the complex system

$$\underline{Aw} + \underline{a} = \underline{0} \tag{3-87}$$

where

$$A = \begin{pmatrix} 1 & j \\ 1 & 1 \end{pmatrix}$$

$$\underline{a} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$
(3-88)

We wish to determine \underline{w} which minimizes the performance index

$$J(\underline{w}) = \|\underline{A}\underline{w} + \underline{a}\|^2 \tag{3-89}$$

that is, the value of \underline{w} at which the "complex gradient" $\nabla_{\underline{w}} J(\underline{w})$ vanishes. This leads to the linear system

$$C\underline{\mathbf{w}} + \underline{\mathbf{b}} = \underline{\mathbf{0}} \tag{3-90}$$

where

$$C = A^{*T}A$$

$$= \begin{pmatrix} 1 & 1 \\ -j & 1 \end{pmatrix} \begin{pmatrix} 1 & j \\ 1 & 1 \end{pmatrix}$$

$$= \begin{pmatrix} 2 & 1+j \\ 1-j & 2 \end{pmatrix}$$

$$= \begin{pmatrix} 1 & 1 \\ -j & 1 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

$$= \begin{pmatrix} 1 \\ -j \end{pmatrix}$$

$$= \begin{pmatrix} 1 \\ -j \end{pmatrix}$$

$$(3-92)$$

We will solve (3-90) for \underline{w} by the following three methods.

Inversion Solution:

By inspection,

$$C^{-1} = \frac{1}{2} \begin{pmatrix} 2 & -(1+j) \\ -(1-j) & 2 \end{pmatrix}$$
 (3-93)

so that, the desired unique solution to (3-90) is given by

$$\underline{w} = -C^{-1}\underline{b}$$

$$= -\frac{1}{2} \begin{pmatrix} 2 & -(1+j) \\ -(1-j) & 2 \end{pmatrix} \begin{pmatrix} 1 \\ -j \end{pmatrix}$$

$$= -\frac{1}{2} \binom{1+j}{-(1+j)}$$

$$= -\frac{1+j}{2} \binom{1}{-1}$$
(3-94)

which happens to satisfy (3-87) and certainly (3-90).

CD Solution:

Below we will use Theorem 3-7 and Lemma 3-8. First, choose basis vectors

$$\underline{q}^0 = [1 \ 0]^T$$
 (3-95.1)

$$\underline{q}^1 = [0 \ 1]^T$$
 (3-95.2)

Then, construct C-conjugate vectors \underline{p}^0 and \underline{p}^1 according to Theorem 3-9, as follows:

$$\underline{p}^0 \approx \underline{q}^0 \tag{3-96.1}$$

$$\underline{p}^1 \approx \underline{q}^1 + \beta_0 \underline{p}^0$$
 (3-96.2)

where, by (3-44)

$$\beta_0 = -\frac{(\underline{q}^1, \underline{cp}^0)^{\frac{1}{2}}}{(\underline{p}^0, \underline{cp}^0)}$$

$$= -\frac{(\underline{1+j})}{2} \qquad (3-97)$$

since, by (3-95) and (3-96)

$$(\underline{q}^1, \underline{cp}^0) = \begin{pmatrix} 0 \\ 1 \end{pmatrix}^T \begin{pmatrix} 2 \\ 1-i \end{pmatrix} = 1-i$$

$$(\underline{p}^0, C\underline{p}^0) = \begin{pmatrix} 1 \\ 0 \end{pmatrix}^T \begin{pmatrix} 2 \\ 1-j \end{pmatrix} = 2$$

Hence, by (3-96),

$$\underline{p}^{0} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

$$\underline{p}^{1} = \begin{pmatrix} 0 \\ 1 \end{pmatrix} - \frac{1+j}{2} \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$
(3-98.1)

$$= \frac{1}{2} \begin{pmatrix} -(1+j) \\ 2 \end{pmatrix}$$
 (3-98.2)

Letting $\underline{w}^0 = \underline{0}$ and thus $\underline{r}^0 = \underline{b}$, we follow the CD process as defined by (3-40). In fact,

$$\alpha_{0} = \frac{(\underline{p}^{0}, \underline{r}^{0})}{(\underline{p}^{0}, \underline{c}\underline{p}^{0})}$$

$$= \frac{1}{2} \binom{1}{0}^{T} \binom{1}{-j}$$

$$= \frac{1}{2} \tag{3-99}$$

and

$$\underline{\mathbf{r}}^1 = \underline{\mathbf{r}}^0 - \alpha_0 C \underline{\mathbf{p}}^0$$

$$= \begin{pmatrix} 1 \\ -j \end{pmatrix} - \frac{1}{2} \begin{pmatrix} 2 \\ 1-j \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} 0 \\ -(1+j) \end{pmatrix}$$
(3-100)

Since

$$c\underline{p}^{1} = \frac{1}{2} \begin{pmatrix} 2 & 1+j \\ 1-j & 2 \end{pmatrix} \begin{pmatrix} -(1+j) \\ 2 \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

then

$$\alpha_{1} = \frac{(\underline{p}^{1}, \underline{r}^{1})}{(\underline{p}^{1}, \underline{c}\underline{p}^{1})}$$

$$= \frac{1}{4} {\binom{-(1-j)}{2}}^{T} {\binom{0}{-(1+j)}}$$

$$= \frac{-1}{2} (1+j) \qquad (3-101)$$

and

$$\underline{r}^{2} = \underline{r}^{1} - \alpha_{1}^{0}\underline{c}\underline{p}^{1}$$

$$= \frac{1}{2} \binom{0}{-(1+j)} + \frac{1}{2} (1+j) \binom{0}{1}$$
(3-102)

Finally, the desired unique solution is given by

$$\underline{\hat{w}} = \underline{w}^0 - \alpha_0 \underline{p}^0 - \alpha_1 \underline{p}^1$$

$$= \binom{0}{0} - \frac{1}{2} \binom{1}{0} + \frac{1}{4} (1+j) \binom{-(1+j)}{2}$$

$$= -\frac{1+j}{2} \binom{1}{-1}$$
(3-103)

which is identical to the inversion solution, (3-94).

In this simple example it is possible to cite, specifically, a number of features that characterize the CD procedure. By (3-101), we have substantiated the fact that, in the CD method, the relaxation coefficient, α , is generally complex - an observation made in the proof of Theorem 3-14.

Another important property of the general CD method is the diagonalization of matrix C via the transformation.

$$D = P^{*T}CP$$

$$= (\underline{p}^{0} \ \underline{p}^{1})^{*T}C(\underline{p}^{0} \ \underline{p}^{1})$$

$$= \begin{pmatrix} 2 & 0 \\ 0 & 1 \end{pmatrix}$$
(3-104)

which is simply a manifestation of the <u>C-conjugacy property</u>. It should be emphasized here that \underline{p}^0 and \underline{p}^1 are not eigenvectors of C, and D is not its eigenvalue matrix. Actually, the eigenvalues of C are $2+\sqrt{2}$ and $2-\sqrt{2}$.

The descent-property may be quantified by direct substitution of \underline{w}^0 , $\underline{w}^2 = \underline{w}^0 - \alpha_0 \underline{p}^0$ and $\underline{w}^2 = \underline{\hat{w}}$ into the quadratic performance index (3-89). The three corresponding successive values of (3-89) are found to be

$$J_0 = J(\underline{w}^0)$$

$$= ||\underline{a}||^2$$

$$= 1 \qquad (3-105.1)$$

$$J_{1} = J(\underline{w}^{1})$$

$$= \| \underline{A}\underline{w}^{1} + \underline{a} \|^{2}$$

$$= \| -\frac{1}{2} \begin{pmatrix} 1 \\ 1 \end{pmatrix} + \begin{pmatrix} 1 \\ 0 \end{pmatrix} \|^{2}$$

$$= \| \frac{1}{2} \begin{pmatrix} 1 \\ -1 \end{pmatrix} \|^{2}$$

$$= \frac{1}{2}$$
(3-105.2)

which, by (3-89), could have been computed by the equivalent relation

$$J_{1} = (\underline{w}^{1},\underline{r}^{1}) + (\underline{w}^{1},\underline{b})^{*} + J_{0}$$
 (3-105.3)

Since we have already shown that

$$J_2 = J(\underline{w}^2) = 0$$
 (3-105.4)

we have illustrated the descent property for the general CD method; namely, $J_0 > J_1 > J_2$.

A final property of the CD method which may be demonstrated in the present example is the construction of the intrinsic inverse, C^{X} . By (3-77).

$$c^{x} = \frac{p^{0}p^{0^{\frac{1}{4}}}}{(p^{0}, cp^{0})} - \frac{p^{1}p^{1^{\frac{1}{4}}}}{(p^{1}, cp^{1})}$$

$$= \frac{1}{2} \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} - \frac{1}{4} \begin{pmatrix} 2 & -2(1+j) \\ -2(1-j) & 4 \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} 2 & -(1+j) \\ -(1-j) & 2 \end{pmatrix}$$
(3-106)

Note that, in this case, $C^{X} = C^{-1}$, the inverse given in (3-93).

CG Solution:

Here, we will use the conventional form of the CG method as given in (3-53) of Theorem (3-9). Starting with <u>initial conditions</u>,

$$\frac{\underline{\mathbf{w}}^{0}}{\underline{\mathbf{p}}^{0}} = \underline{\mathbf{r}}^{0} = \underline{\mathbf{b}} = \begin{pmatrix} 1 \\ -\mathbf{j} \end{pmatrix} .$$
(3-107)

and $\|\underline{r}^0\|^2 \approx 2$, we proceed with the first iteration. Since

$$C\underline{p}^{0} = \begin{pmatrix} 2 & 1+j \\ 1-j & 2 \end{pmatrix} \begin{pmatrix} 1 \\ -j \end{pmatrix} = \begin{pmatrix} 3-j \\ 1-3j \end{pmatrix}$$

$$(\underline{p}^0, \underline{c}\underline{p}^0) = \begin{pmatrix} 1 \\ j \end{pmatrix}^T \begin{pmatrix} 3-j \\ 1-3j \end{pmatrix} = 6$$

then,

$$\alpha_0 = \frac{\|\mathbf{r}^0\|^2}{(\mathbf{p}^0, \mathbf{c}\mathbf{p}^0)}$$

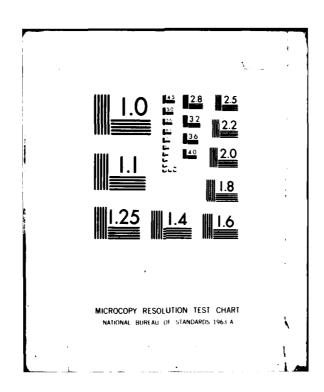
$$= \frac{1}{3} \tag{3-108}$$

$$\underline{w}^{1} = \underline{w}^{0} - \alpha_{0}\underline{p}^{0}$$

$$= \underline{0} - \frac{1}{3} \begin{pmatrix} 1 \\ -j \end{pmatrix}$$

$$= \frac{1}{3} \begin{pmatrix} -1 \\ j \end{pmatrix}$$
(3.109)

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$$\underline{\underline{r}}^{1} = \underline{\underline{r}}^{0} - \alpha_{0} \underline{c} \underline{p}^{0}$$

$$= \begin{pmatrix} 1 \\ -j \end{pmatrix} - \frac{1}{3} \begin{pmatrix} 3-j \\ 1-3j \end{pmatrix}$$

$$= \frac{1}{3} \begin{pmatrix} 1 \\ -j \end{pmatrix}$$
(3-110)

$$\beta_{0} = \frac{\|\underline{r}^{1}\|^{2}}{\|\underline{r}^{0}\|^{2}}$$

$$= \left(\frac{2}{9}\right) \left(\frac{1}{2}\right)$$

$$= \frac{1}{9} \tag{3-111}$$

and

$$\underline{p}^{1} = \underline{r}^{1} + \beta_{0}\underline{p}^{0}$$

$$= \frac{1}{3} \binom{j}{-1} + \frac{1}{9} \binom{1}{-j}$$

$$= \frac{1}{9} \binom{1+3j}{-(3+j)}$$
(3-112)

In the second iteration, since

$$Cp^{1} = \frac{1}{9} \begin{pmatrix} 2 & 1+j \\ 1-j & 2 \end{pmatrix} \begin{pmatrix} 3j+1 \\ -(3+j) \end{pmatrix}$$

$$= \frac{1}{9} \begin{pmatrix} 2(3j+1) - (1+j)(3+j) \\ (1-j)(3j+1) - 2(3+j) \end{pmatrix}$$

$$= \frac{2}{9} \begin{pmatrix} j \\ -1 \end{pmatrix}$$

IV-57

$$(p^{1}, cp^{1}) = \frac{2}{81} {\begin{pmatrix} 1-3j \\ -3+j \end{pmatrix}}^{T} {\begin{pmatrix} j \\ -1 \end{pmatrix}}$$
$$= {\begin{pmatrix} \frac{2}{81} \end{pmatrix}} 6$$
$$= \frac{4}{27}$$

then,

$$\alpha_{1} = \frac{\|\underline{\mathbf{r}}^{1}\|^{2}}{(\underline{\mathbf{p}}^{1}, \underline{\mathbf{c}}\underline{\mathbf{p}}^{1})}$$

$$= \left(\frac{2}{9}\right) \left(\frac{27}{4}\right)$$

$$= \frac{3}{2}$$

$$\underline{\mathbf{w}}^{2} = \underline{\mathbf{w}}^{1} - \alpha_{1}\underline{\mathbf{p}}^{1}$$

$$= \frac{\sqrt{-1}}{2} \qquad (3-113)$$

$$= \frac{1}{3} {\binom{-1}{j}} - {\left(\frac{3}{2}\right)} {\left(\frac{1}{9}\right)} {\binom{1+3j}{-(j+3)}}$$

$$= \frac{1}{3} {\binom{-1}{j}} - \frac{1}{6} {\binom{1+3j}{-3-j}}$$

$$= \frac{1}{6} {\binom{-3-3j}{3+3j}}$$

$$= \frac{1+j}{2} {\binom{1}{-1}}$$
(3-114)

$$\underline{\underline{r}}^{2} = \underline{\underline{r}}^{1} - \alpha_{1} \underline{c} \underline{\underline{p}}^{1}$$

$$= \frac{1}{3} \binom{j}{-1} - \left(\frac{3}{2}\right) \left(\frac{2}{9}\right) \binom{j}{-1}$$

$$= \underline{0}$$
(3-115)

The CG process is terminated at this point of the second iteration, since $\|\underline{r}^2\| = \underline{0}$. Obviously, $\underline{\hat{w}} = \underline{w}^2$, which agrees with previous results, (3-94) and (3-103).

As a consequence of this example, it is possible to cite some specific properties of the CG method. In contrast to the CD method, the relaxation coefficient, α , in the CG method is always real.

As expected, the $\underline{\text{C-conjugacy property}}$ in the CG method gives rise to the $\underline{\text{diagonalization of }}$ $\underline{\text{matrix C}}$ via the transformation

$$D = P^{*T}CP$$

$$= (\underline{p}^{0} \underline{p}^{1})^{*T}C(\underline{p}^{0} \underline{p}^{1})$$

$$= \begin{pmatrix} 6 & 0 \\ 0 & 4/27 \end{pmatrix}$$
(3-116)

Note that this value of D is different from that of (3-104) in the CD solution. Similarly, p^0 and p^1 are not eigenvectors of C, and D is not its eigenvalue matrix.

The descent property of the CG method may also be demonstrated. At the initial estimate, $\underline{w}^0 = \underline{0}$, the performance index value is

$$J_0 = 1$$
 (3-117.1)

as in the CD case. At the first iterate, \underline{w}^1 ,

$$J_{1} = J(\underline{w}^{1})$$

$$= \| \underline{A}\underline{w}^{1} + \underline{a} \|^{2}$$

$$= \| \frac{1}{3} \begin{pmatrix} 1 & j \\ 1 & 1 \end{pmatrix} \begin{pmatrix} -1 \\ j \end{pmatrix} + \begin{pmatrix} 1 \\ 0 \end{pmatrix} \|^{2}$$

$$= \| \frac{1}{3} \begin{pmatrix} -2 \\ -1+j \end{pmatrix} + \begin{pmatrix} 1 \\ 0 \end{pmatrix} \|^{2}$$

$$= \| \frac{1}{9} \begin{pmatrix} 1 \\ -1+j \end{pmatrix} \|^{2}$$

$$= \frac{1}{3}$$
(3-117.2)

or, equivalently, by (3-89)

$$J^{1} = (\underline{w}^{1}, \underline{r}^{1}) + (\underline{w}^{1}, \underline{b}) * + J_{0}$$

$$= \frac{1}{9} {\binom{-1}{-j}}^{T} {\binom{j}{-1}} + \frac{1}{3} {\binom{-1}{j}}^{T} {\binom{1}{j}} + 1$$

$$= 0 - \frac{2}{3} + 1$$

$$= \frac{1}{3}$$
(3-117.2)

and, as before,

$$J_2 = 0 (3-117.3)$$

Clearly, $J_0 > J_1 > J_2$, as in the CD case. In comparison, J_1 is smaller in the CG case because the relaxation is along $-\underline{r}^0$, the direction of steepest descent.

The CG intrinsic inverse may now be computed by using (3-77). In fact,

$$c^{X} = \frac{p^{0}p^{0}x^{T}}{(p^{0}, cp^{0})} + \frac{p^{1}p^{1}x^{T}}{(p^{1}, cp^{1})}$$

$$= \frac{1}{6} \binom{1}{-j} \binom{1}{1} + \binom{27}{4} \binom{1}{81} \binom{1+3j}{-(3+j)} \binom{1-3j}{1-3j} - (3-j)$$

$$= \frac{1}{6} \binom{1}{-j} + \frac{1}{12} \binom{10}{-6} - 6-8j \binom{1}{-6} + 8j = 10$$

$$= \frac{1}{12} \binom{12}{-6(1-j)} - \frac{12}{12}$$

$$= \frac{1}{2} \binom{2}{-(1-j)} - \frac{2}{2}$$
(3-118)

which happens to be the inverse, C^{-1} , in (3-93).

It should be noted that the CG procedure took 2 iterations to produce the solution, which corresponds to the rank matrix C. The probability that it could have terminated in one iteration is zero since the eigenvalues of C are distinct and \underline{b} is a linear combination of the two associated eigenvectors. The latter claim follows directly from the initial discussion in Section 2.2.2.3.

3.3.2 Singular Covariance Case

Consider next a simple example of a singular system (3-87), where

$$A = \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}$$

$$\underline{a} = \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

$$(3-119)$$

We wish to solve (3-90), where

$$C = 2 \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} \tag{3-120}$$

$$\underline{\mathbf{b}} = 2 \begin{pmatrix} 1 \\ 1 \end{pmatrix} \tag{3-121}$$

Since C is clearly singular, an inversion solution is not possible. Below, we will solve (3-90) with the C and \underline{b} values given above via the approximate regularized inverse, the pseudoinverse, CD and CG.

Regularized Inversion Schedule:

With reference to Section 2.2.1.1, define the regularized matrix C by

$$\tilde{C} = 2 \begin{pmatrix} 1+\varepsilon & 1 \\ 1 & 1+\varepsilon \end{pmatrix}$$
 (3-122)

Then, the regularized inverse is simply

$$C^{-1} = \frac{1}{2\varepsilon(2+\varepsilon)} \begin{pmatrix} 1+\varepsilon & -1 \\ -1 & 1+\varepsilon \end{pmatrix}$$
 (3-123)

whence,

$$\frac{\tilde{w}}{\tilde{w}} = -\tilde{C}^{-1}\underline{b}$$

$$= -\frac{1}{(2+\epsilon)} \begin{pmatrix} 1 \\ 1 \end{pmatrix}.$$
(3-124)

At this regularized inverse solution, the performance index (3-89) becomes

$$J(\underline{\widetilde{w}}) = \|\underline{A}\underline{\widetilde{w}} + \underline{a}\|^{2}$$

$$= \left\|-\frac{1}{2+\epsilon} \binom{2}{2} + \binom{1}{1}\right\|^{2}$$

$$= \left(\frac{1}{\varepsilon+2}\right)^2 \quad 2\varepsilon^2$$

$$= 2\left(\frac{\varepsilon}{\varepsilon+2}\right)^2$$

$$\approx \frac{\varepsilon^2}{2} \tag{3-125}$$

when $\varepsilon \ll 1$. Note that

$$\lim_{\varepsilon \to 0} \frac{\widetilde{w}}{\varepsilon} = -\frac{1}{2} \binom{1}{1} \tag{3-126}$$

at which value $J(\tilde{w}) = 0$. Clearly then, (3-126) is the minimum-norm solution which may be obtained by pseudoinversion according to Theorem 2-1.

Pseudoinversion Solution:

The eigenvalues of C, given by (3-120), satisfy the characteristic equation

$$0 = \phi(\lambda)$$

$$= \det |C-\lambda I|$$

$$= (\lambda-2)^2 - 4$$

$$= \lambda^2 - 4\lambda \qquad (3-127)$$

The actual eigenvalues are λ_1 = 4 and λ_2 = 0, the latter indicative of the singularity of C. The corresponding eigenvectors are \underline{e}^1 = $(1/\sqrt{2})[1 \ 1]^T$ \underline{e}^2 = $(1/\sqrt{2})[1 \ -1]^T$. Then, by (2-26) in Theorem 2-1

$$C = E \Lambda^{\dagger} E^{\dagger}^{T}$$

$$= 2 \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} 2 & 0 \\ 0 & 0 \end{pmatrix} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$
(3-128)

and by (2-30), the pseudoinverse of C in given by

$$C^{+} = E \Lambda^{+} E^{+T}$$

$$= \frac{1}{8} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

$$= \frac{1}{8} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} 1 & 1 \\ 0 & 0 \end{pmatrix}$$

$$= \frac{1}{8} \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} \qquad (3-129)$$

so that, by (2-32), the minimum-norm solution is

$$\frac{\hat{\mathbf{w}}}{1} = -\mathbf{c}^{\dagger}\underline{\mathbf{b}}$$

$$= -\frac{1}{4} \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

$$= -\frac{1}{2} \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$
(3-130)

which agrees with the limiting regularized solution (3-126).

CD Solution:

To solve (3-90) with C, \underline{b} as defined in (3-120) and (3-121), we will use the basis vectors (3-95) and C-conjugate vector expressions (3-96). As in the previous example, since

$$(\underline{q}^1, \underline{cp}^0) = 2 \begin{pmatrix} 0 \\ 1 \end{pmatrix}^T \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \end{pmatrix} = 2$$

$$(\underline{p}^0, \underline{cp}^0) = 2 \begin{pmatrix} 1 \\ 0 \end{pmatrix}^T \begin{pmatrix} 1 \\ 1 \end{pmatrix} = 2$$

then, by (3-44)

$$\beta_0 = -\frac{(\underline{q}^1, \underline{c}\underline{p}^0)^{\frac{1}{10}}}{(\underline{p}^0, \underline{c}\underline{p}^0)}$$

$$= -1 \tag{3-131}$$

so that, by (3-96)

$$\underline{p}^{0} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \qquad (3-132.1)$$

$$\underline{p}^{1} = \begin{pmatrix} 0 \\ 1 \end{pmatrix} - \begin{pmatrix} 1 \\ 0 \end{pmatrix} \qquad (3-132.2)$$

With $\underline{\mathbf{w}}^0 = \underline{\mathbf{0}}$ and thus $\underline{\mathbf{r}}^0 = \underline{\mathbf{b}}$, we follow CD process (3-40):

$$\alpha_0 = \frac{(\underline{p}^0, \underline{r}^0)}{(\underline{p}^0, \underline{c}\underline{p}^0)}$$

$$= \frac{1}{2} {1 \choose 0}^T 2 {1 \choose 1}$$

$$= 1 \qquad (3-133)$$

and

•

$$\underline{r}^{1} = \underline{r}^{0} - \alpha_{0} \underline{c} \underline{p}^{0}$$

$$= 2 \binom{1}{1} - 2 \binom{1}{1}$$

$$= \underline{0} \qquad (3-134)$$

at which point, the CD process terminates. The one-iteration solution is then

$$\frac{\hat{\mathbf{w}}}{\mathbf{w}} = \underline{\mathbf{w}}^{0} - \alpha_{0} \underline{\mathbf{p}}^{0}$$

$$= -\binom{1}{0}$$
(3-135)

Note that this solution is a generalized solution and not the minimum-norm solution (3-130). In fact, the norm of solution (3-135) is 1, which is greater than the minimum-norm of $\sqrt{2}/2$. Of course, either solution satisfies (3-90) with C and <u>b</u> values given in (3-120) and (3-121).

As expected, even in this singular example, the <u>C-conjugacy</u> property leads to the <u>diagonalization of matrix C</u> via the transformation

$$D = P^{*T}CP$$

$$= (p^{0} p^{1})^{*T}C(p^{0} p^{1})$$

$$= 2 \binom{1}{1} \binom{1}{1} \binom{1}{1} \binom{1}{0} \binom{1}{1}$$

$$= 2 \binom{1}{-1} \binom{1}{1} \binom{1}{1} \binom{0}{1}$$

$$= \binom{2}{0} \binom{0}{0}$$
(3-136)

The fact that 2 is the nontrivial eigenvalue of C in the present example is coincidental with the choice of basis vectors in the CD process. Certainly, \mathbf{p}^0 and \mathbf{p}^1 are not eigenvectors of C.

The descent property is obvious in this case. Since $J_0 = 2$ and $J_1 = 0$, $J_0 > \overline{J_1}$ holds.

The <u>CD intrinsic inverse</u>, C^x, as defined by (3-77) is computed

$$c^{X} = \frac{\underline{p}^{0} \ \underline{p}^{0 + T}}{(\underline{p}^{0}, \underline{c}\underline{p}^{0})}$$

$$= \frac{1}{2} \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$$
(3-137)

which, interestingly, is twice as large as the pseudoinverse (3-129). Note that since C^X is not equal to the pseudoinverse, it is a generalized inverse. If \underline{p}^0 were chosen equal to the nontrivial eigenvector $\underline{e}^1 = [1 \quad 1]^T$, C^X would be identical to the pseudoinverse.

CG Solution:

to be

Starting with initial conditions

$$\underline{\mathbf{w}}^{0} = \underline{\mathbf{0}} \\
\underline{\mathbf{p}}^{0} = \underline{\mathbf{r}}^{0} = \underline{\mathbf{b}}$$
(3-138)

and $\|\underline{r}^0\|^2 = 8$, we solve (3-90) for the C and \underline{b} values defined in (3-120) and (3-121). Since

$$C\underline{p}^{0} = 4\begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}\begin{pmatrix} 1 \\ 1 \end{pmatrix} = 8\begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

$$(\underline{p}^{0}, \underline{cp}^{0}) = 16 \binom{1}{1}^{T} \binom{1}{1} = 32$$
 (3-139)

then.

$$\alpha_0 = \frac{\|\underline{r}^0\|^2}{(\underline{p}^0, C\underline{p}^0)}$$

$$= \frac{1}{\mu}$$
(3-140)

$$\underline{\underline{w}}^{1} = \underline{\underline{w}}^{0} - \alpha_{0}\underline{\underline{p}}^{0}$$

$$= -\frac{1}{2} \binom{1}{1} \qquad (3-141)$$

$$\underline{r}^{1} = \underline{r}^{0} - \alpha_{0} C \underline{p}^{0}$$

$$= 2 \binom{1}{1} - \frac{1}{4} (8) \binom{1}{1}$$

$$= 0 \qquad (3-142)$$

at which point the CG process terminates. Clearly, $\frac{\hat{w}}{w} = \underline{w}^1$, which happens to be the minimum-norm solution, (3-130). This is as expected, since $\underline{w}^0 = \underline{0} \in C^{\mathbb{R}}$.

As expected, the $\underline{\text{C-conjugacy property}}$ leads to the diagonalization of matrix C; i.e.,

$$D = P^{*T}CP$$

$$= (p^{0} p^{1})^{*T}C(p^{0} p^{1})$$

$$= \begin{pmatrix} 32 & 0 \\ 0 & 0 \end{pmatrix}$$
(3-143)

The descent property is obvious since $J_0 = 2$ and $J_1 = 0$ and $J_0 > J_1$ holds.

The CG intrinsic inverse is given by

and the state of t

$$c^{\times} = \frac{p^{0} p^{0 * T}}{(p^{0}, cp^{0})}$$

$$= \frac{1}{8} \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}$$
(3-144)

which happens to be identical to the <u>pseudoinverse</u>, (3-129). Again, this is as expected, since $\underline{w}^0 = \underline{0}$ and $\underline{p}^0 = \underline{b} \in \mathbb{C}^p$.

4.0 CONSTRAINED BATCH ADAPTIVE PROCESSING

Recall that, in the sidelobe cancellation system under consideration, a number of omnidirectional auxiliary antenna elements are adaptively weighted and combined with an established narrow-beam main antenna array. In so doing, it is inevitable that the original mainbeam gain will not remain intact. While this effect is expected when undesired sidelobe interference is present, it could be more pronounced if a desired signal of significant relative power is incident along the mainbeam direction. As the number of adjustable auxiliaries increases, this problem becomes correspondingly more important.

What is needed to alleviate an undesired variation in mainbeam signal gain is an appropriate constraint on the adaptive weights applied over the auxiliaries. Conceptually, one such approach would consist of guaranteeing that the gain contribution by the auxiliary subarray in the mainbeam direction remain fixed during system operation. The appropriate criterion would then be minimum-combined-power subject to a fixed auxiliary subarray gain constraint. In mathematical terms, this may be stated as the constrained minimization problem

$$\begin{array}{cc}
\min & P_{c}(\underline{w}) \\
\underline{w}
\end{array} (4-1.1)$$

subject to:
$$(\underline{e},\underline{w}) = d$$
 (4-1.2)

where

$$P_{C}(\underline{w}) = \|\underline{s}^{T}\underline{w} + s_{0}\|^{2}$$

= the combined signal power over an
M-sample batch

d = a fixed real gain of the auxiliary subarray
along the mainbeam direction

e = a nonzero complex constraining N-vector on the auxiliary weight vector w which guarantees a fixed auxiliary subarray gain d in the mainbeam direction

Note that (4-1) is a general enough statement to encompass the fully-adaptive problem. In fact, in the absence of a main antenna, which corresponds to $s_{A} = 0$, (4-1) states the adaptive beamforming problem [8].

The discussion that follows presents the conventional approach for solving (4-1) based on the Lagrange-multiplier (LM) method [9] and involving the inversion of the covariance matrix $C = \langle \underline{s}, \underline{s}^T \rangle$. However, when C^{-1} does not exist, this approach is not valid. The constrained BCR formulation is introduced as a means of circumventing the need to invert C. More specifically, a detailed mathematical development of the constrained CD method (CCD) precedes the specific constrained CG method (CCG). Numerical examples are used to contrast the inversion and relaxation approaches.

4.1 Lagrange-Multiplier Method

The solution to (4-1) may be obtained by the minimization of the Lagrangian function

$$L(\underline{w}, \lambda_1, \lambda_2) = \frac{1}{2} P_{C}(\underline{w}) + \lambda_1 (Re(\underline{e}, \underline{w}) - d) + \lambda_2 (Im(\underline{e}, \underline{w}))$$
 (4-2)

with respect to \underline{w} and the real-valued Lagrange multipliers, λ_1 and λ_2 . This involves solving the complex linear system that results from setting the complex gradient, $\nabla_{\underline{w}} L(\underline{w}, \lambda_1, \lambda_2)$, to zero simultaneously with the equality constraint. The resulting constrained solution, $\underline{\hat{w}}^C$, is defined in the following theorem.

Theorem 4-1. [Lagrange-Multiplier Solution to the Linearly Constrained Adaptive Nulling Problem, (4-1)]

The Lagrange-multiplier solution to (4-1), based on the Lagrangian function (4-2) is given by

$$\widehat{\mathbf{w}}^{\mathsf{c}} = \widehat{\mathbf{w}} - \lambda \mathbf{C}^{-1} \mathbf{e} \tag{4-3}$$

where

$$\underline{\alpha} = -C^{-1}\underline{b} \tag{4-4}$$

= the familiar unconstrained inversion solution

$$\lambda = \lambda_1 + j\lambda_2 \tag{4-5.1}$$

$$= -\frac{d - (e, \hat{w})}{(e, C^{-1}e)}$$
 (4-5.2)

for any $e \in C^N$, provided that C^{-1} exists.

<u>Proof</u>: Setting the "complex gradient" $\nabla_{\underline{w}} L(\underline{w}, \lambda_1, \lambda_2)$ to zero, we get

$$\underline{0} = C\underline{w} + \underline{b} + \lambda_{1}\underline{e} + j\lambda_{2}\underline{e}$$

$$= C\underline{w} + \underline{b} + \lambda\underline{e}$$
(4-6)

where λ is given by (4-5.1). Then, given that C^{-1} exists, the desired constrained solution (4-3) follows immediately, in view of (4-4). Upon substituting (4-3) into constraint equation (4-1.2) we get the composite complex Lagrange multiplier solution. In fact,

$$d = (\underline{e}, \hat{\underline{u}}^{C})$$

$$= (\underline{e}, \hat{\underline{u}}) - \lambda(\underline{e}, C^{-1}\underline{e})$$
(4-7)

which yields the desired result, (4-5.2).

Based on Theorem 4-1 we can derive the solution for the special fully-adaptive or adaptive beamforming problem [10]. This is stated in the corollary that follows.

Corollary 4-2. [Lagrange-Multiplier Solution to the Fully-Adaptive Problem, (4-1)]

Consider the fully-adaptive special case of (4-1). In the absence of a fixed main antenna, $\underline{b} = \underline{0}$. Then, assuming C⁻¹ exists, the Lagrange-multiplier solution to (4-1) is given by

$$\underline{\underline{\alpha}}^{c} = \frac{d}{(\underline{e}, c^{-1}\underline{e})} c^{-1}\underline{e}$$
 (4-8)

for any $e \in C^N$, provided that C^{-1} exists.

<u>Proof:</u> When b = 0, $w = -C^{-1}b = 0$. Then, the familiar "steering vector" solution (4-8) follows immediately from Theorem 4-1.

Of course, in the above development, there is no particular restriction that d be real. In fact, it may be complex, in general. Of greater concern to the problem at hand is the reliance that ${\tt C}^{-1}$ exist. If ${\tt C}^{-1}$ does not exist, one must resort to alternate approaches^{\dagger}, including regularization of C in which case the inevitable error in solution accuracy must be tolerated.

In line with the main thrust of the work presented here, the constrained problem (4-1) will be addressed via a BCR approach. As such, C^{-1} need not exist.

4.2 Derivation of Constrained BCR (CBCR)

Consider the constrained minimization problem (4-1). Note that the equality constraint (4-1.2) simply states that the desired solution, \hat{w}^c , lies on a constraining hyperplane whose orientation is defined by a normal vector \underline{e} and its normal $\underline{displacement}$ from the origin is determined by d.

More specifically, the desired solution $\underline{\hat{w}}^C$ is a vector which originates from the origin and terminates at a point in the constraining hyperplane at which the combined power $P_C(\underline{w})$ is a minimum. At such a point, the complex gradient $\nabla_w P_C(\underline{w})$ projected on the hyperplane must vanish.

In general, any vector $\underline{v} \in C^N$ may be expressed as an additive composition of two N-vectors, $\underline{v}^{\shortparallel}$ and $\underline{v}^{\intercal}$, its parallel and perpendicular parts with respect to the constraining hyperplane. That is,

$$\underline{\mathbf{v}} = \underline{\mathbf{v}}^{\mathsf{H}} + \underline{\mathbf{v}}^{\mathsf{L}} \tag{4-9}$$

where, by definition,

$$(\underline{\mathbf{e}},\underline{\mathbf{v}}^{"})=0 \tag{4-10.1}$$

$$(\underline{e},\underline{v}) = (\underline{e},\underline{v}^{\perp}) \tag{4-10.2}$$

Private discussions with J. R. Roman, Advanced Technology and Systems Analysis Section, Systems Office, Radar Operations, Motorola Government Electronics Division, Tempe, Arizona.

Then,

$$\underline{\mathbf{v}}^{\parallel} = \underline{\mathbf{v}} - \underline{\mathbf{v}}^{\perp}$$

$$= \underline{\mathbf{v}} - \frac{\underline{\mathbf{e}}}{\|\underline{\mathbf{e}}\|^2} (\underline{\mathbf{e}}, \underline{\mathbf{v}})$$

$$= \left(\mathbf{I} - \frac{\underline{\mathbf{e}} \cdot \underline{\mathbf{e}}^{*T}}{\|\underline{\mathbf{e}}\|^2}\right) \underline{\mathbf{v}}$$

$$= \mathbf{P}\mathbf{v}$$

$$(4-11)$$

where P is the desired projection operator, a unitary N x N matrix.

In view of the above, the constrained minimization of (4-1) leads to the simultaneous system

$$P(Cw + b) = 0$$
 (4-12.1)

$$(e,w) = d$$
 (4-12.2)

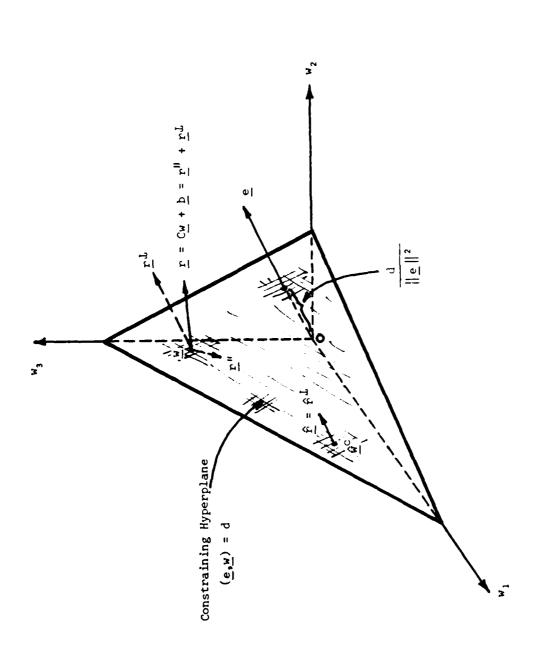
where, (4-12.1) requires that the projected gradient $\nabla_{\mathbf{w}} P_{\mathbf{c}}(\underline{\mathbf{w}})$ vanish at a point $\underline{\mathbf{w}}$, and (4-12.2) forces this $\underline{\mathbf{w}}$ to be a point on the constraining hyperplane. Figure 4-1 serves to demonstrate these results.

With the constrained minimization formulation at hand and the geometrical interpretation provided in Figure 4-1, we wish to appropriately redefine the CD and CG methods for arriving at the desired solution $\hat{\mathbf{w}}^{\text{C}}$. Logically, we wish to choose an initial solution estimate $\underline{\mathbf{w}}^{\text{O}}$ lying on the constraining hyperplane and define CD and CG iterative relaxation procedures that are totally confined on the hyperplane. These two constrained methods are developed in the next two sections.

4.2.1 Constrained CD (CCD) Method

Consider the specialization of the CD method, already developed in Section 2.2.2.1, for solving the linearly constrained problem (4-1), or, more specifically, the equivalent statement (4-12). To begin with, choose an initial solution estimate, \underline{w}^0 , that lies entirely on the constraining hyperplane. That is, choose \underline{w}^0 such that

$$(\underline{e},\underline{w}^0) = d \tag{4-13}$$



Geometrical Interpretation of the Constrained Minimization Formulation (4-12), of Problem (4-1). Figure 4-1.

Then, the desired solution, \hat{w}^c , may be expressed as

$$\underline{\hat{w}}^{c} = \underline{w}^{0} - \sum_{k=0}^{Q-1} \alpha_{k} \underline{p}^{k}$$
 (4-14)

where $0 \le N$, the dimensionality of \underline{w} , $\{\alpha_k\}_{k=0}^{Q-1}$ is a set of expansion coefficients corresponding to a set of linearly independent set of vectors $\{p^k\}_{k=0}^{Q-1}$. With the restrictions that these vectors be parallel to the constraining hyperplane; that is,

$$(\underline{e},\underline{p}^{k}) = \underline{0}$$

$$P\underline{p}^{k} = \underline{p}^{k}$$

$$\forall k \in [0,Q-1]$$
(4-15)

(4-14) is meaningful, since by (4-13) and (4-15)

$$(\underline{\mathbf{e}}, \underline{\hat{\mathbf{w}}}^{\mathbf{C}}) = \mathbf{d} \tag{4-16}$$

as desired. Then, by (4-12.1), the projected gradient will vanish at $\underline{\hat{w}}^{\text{C}}$. Letting

$$\underline{\mathbf{r}}^{0} = P(\underline{\mathbf{c}}\underline{\mathbf{w}}^{0} + \underline{\mathbf{b}}) \tag{4-17}$$

be the projected gradient, or residual, at the initial estimate \underline{w}^0 , (4-14) implies that

$$\underline{0} = \hat{\underline{r}}^{c}$$

$$= \underline{r} - \sum_{k=0}^{Q-1} \alpha_{k}^{p} \underline{c}_{\underline{p}}^{k}$$
(4-18)

We wish to solve for the set of expansion coefficients $\{\alpha_k\}_{k=0}^{Q-1}$. One efficient such solution is specified in the following lemma.

Lemma 4-3. Solution of $\{\alpha_k\}_{k=0}^{Q-1}$ Via PC-Conjugacy of $\{p^k\}_{k=0}^{Q-1}$

There exists a linearly independent set of PC-conjugate vectors $\left\{p^k\right\}_{k=0}^{Q-1}$ such that

$$\alpha_{i} = \frac{(\underline{p}^{i},\underline{r}^{i})}{(\underline{p},\underline{PCp}^{i})}$$

$$\forall i \in [0,Q-1]$$
(4-19)

Proof: By (4-18) and (4-15)

$$(\underline{p}^{i},\underline{r}^{0}) = \sum_{k=0}^{Q-1} \alpha_{k}(\underline{p}^{i},PC\underline{p}^{k})$$
 (4-20)

and

$$(\underline{p}^{i},PC\underline{p}^{k}) = (\underline{p}^{i},PCP\underline{p}^{k})$$
 (4-21)

respectively. Since P and C are conjugate symmetric, PCP is also conjugated symmetric. In fact,

$$(PCP)^{*T} = P^{*T}C^{*T}P^{*T}$$

$$= PCP \qquad (4-22)$$

Then, by Lemmas 3-3 and 3-4, it is possible to assume PCP-conjugacy on the set of linearly independent vectors $\{p^k\}_{k=0}^{Q-1}$. But, (4-21) implies that a PC-conjugacy may be assumed, equivalently. Applying PC-conjugacy on (4-20), we get the desired result.

It is now possible to state one version of the constrained CD method for solving (4-12), the equivalent statement to (4-1).

Theorem 4-4. [Standard Form of the CCD Method]

Consider the system

$$P(Cw + b) = 0$$
 (4-23.1)

$$(e, w) = d$$
 (3-23.2)

where C is an N x N . .plex Hermitian matrix of rank R, \underline{b} is a complex N-vector in C^R , the prespace of C, \underline{e} is a complex constraining N-vector, d is a real-valued so lar, P is a complex N x N unitary matrix

$$P = \frac{e}{|e|^2}$$

$$(4-24)$$

the projection operator which projection of any vector $\underline{v} \in C^N$ onto the hyperplane (4-23.2), and \underline{w} is the complex N-vector to be determined. Let

$$\left\{ \underbrace{p}^{k} \right\} \underset{k=0}{Q-1} \tag{4-25}$$

be a set of Q, Q< R \leq N, linearly independent complex N-vectors having the properties of

(1) Nonzero intersection with PC^{R} , the projected eigenspace of C; i.e.,

$$\underbrace{\mathbf{p}^{\mathbf{i}} \cap \mathbf{PC}^{\mathbf{R}} \neq \emptyset}_{\mathbf{V} \mathbf{i} \in [0, Q-1]} \tag{4-26}$$

(2) Spanning the constrained eigenspace, PCR, via a linear combination; i.e.,

$$PC^{R} = \left\{ P\underline{v} \in C^{N} : Pv = \sum_{i=0}^{Q-1} a_{i}P^{i} ; V \underline{v} \in C^{N}, a_{i} \in C^{1}, i \in [0, Q-1] \right\} (4-27)$$

(3) Mutual PC-conjugacy property, i.e.,

$$(p^{i}, Pcp^{j}) = 0$$

 $\forall i, j \in [0, Q-1]; i \neq j$ (4-28)

Then, a general solution to (4-31) is the last iterate, \underline{w}^{Q-1} , of the Q-step iterative procedure that begins with an initial solution estimate, \underline{w}^0 that satisfies (4-23.2) and a corresponding residual vector $\underline{r}^0 = P(C\underline{w}^0 + \underline{b})$ and repeats relations

$$a_{i} = \frac{(\underline{p}^{i}, \underline{r}^{0})}{(\underline{p}^{i}, PC\underline{p}^{i})}$$
 (4-29.1)

$$\underline{\underline{w}}^{i+1} = \underline{\underline{w}}^{i} - \alpha_{i}\underline{\underline{p}}^{i}$$
 (4-29.2)

$$\underline{r}^{i+1} = \underline{r}^{i} - \alpha_{i} PC\underline{p}^{i}$$
 (4-29.3)

for i = 0, 1, ..., Q-1. This procedure will be referred to as the standard form of the constrained conjugate direction (CCD) method.

<u>Proof:</u> Relation (4-29.1) is that already proved in the discussion preceeding this theorem. Referring to (4-14) it is possible to identify a sequence of solution estimates $\left\{ \begin{array}{l} w^k \\ k = 0 \end{array} \right\}$ such that witl is given by (4-29.2). Upon substituting (4-29.2) we can define a corresponding sequence of residuals, $\left\{ \begin{array}{l} r^k \\ k = 0 \end{array} \right\}$, such that, ritl is given by (4-29.3). The hypotheses stated are similar to those of Theorem 3-5 except for the modifications needed to incorporate the projection operator. Finally, note that since the constraining vector \underline{e} is eliminated from the set $\left\{ \underline{p^i} \right\}_{i=0}^{Q-1}$, $Q \leq R-1$.

An alternate form of the CCD method that is numerically more robust may be derived by using the following lemma.

Lemma 4-5. [Special Properties of (p^i, r^j) in the CCD Method]

In the CCD method as defined by Theorem 4-4, the ineer product $(\underline{p}^i,\underline{r}^j)$ has the following properties

$$\left\{ \begin{array}{l} (\underline{p}^{i},\underline{r}^{j}) = (\underline{p}^{i},\underline{r}^{0}) \\ \forall i \geq j \; ; \; i,j \in [0,Q-1] \end{array} \right\}$$
(4-30)

and

$$(\underline{p}^{i},\underline{r}^{i}) = 0$$
 (4-31)
 $\forall i < j ; i \in [0, Q-1], j \in [1, Q-1]$

<u>Proof:</u> Given the PC-conjugacy condition (4-28) and recursion (4-29.3), results (4-30) and (4-31) follow in the same way as those of Lemma 3-6.

The alternate form of the CCD algorithm may now be stated in the following theorem.

Theorem 4-6. [Alternate Form of the CCD Method]

Given all the hypothesis of Theorem 4-4, a general solution to (4-23) is the iterate, \underline{w}^{Q-1} , of the Q-step iterative procedure that begins with an arbitrary initial estimate, \underline{w}^0 , in the constraining hyperplane (4-23.2) and the corresponding residual vector, $\underline{r}^0 = P(C\underline{w}^0 + \underline{b})$, and, upon setting $\underline{p}^0 = \underline{r}^0$, repeats relations

$$\alpha_{i} = \frac{(\underline{p}^{i}, \underline{r}^{i})}{(\underline{p}^{i}, PC\underline{p}^{i})}$$
(4-32.1)

$$\underline{\underline{w}}^{i+1} = \underline{\underline{w}}^{i} - \alpha_{i}\underline{p}^{i}$$
 (4-32.2)

$$\underline{\mathbf{r}}^{\mathbf{i}+1} = \underline{\mathbf{r}}^{\mathbf{i}} - \alpha_{\mathbf{i}}^{\mathbf{P}} \mathbf{C} \underline{\mathbf{p}}^{\mathbf{i}}$$
 (4-32.3)

for i = 0, 1, ..., Q-1. This procedure will be referred to as the <u>alternate</u> form of the constrained conjugate directions (CCD) method.

Proof: Result (4-32) follows from Theorem 4-4 and Lemma 4-5.

Of course, a means for constructing the set of PC-conjugate set of vectors $\{p^i\}_{i=0}^{Q-1}$ is crucial to the complete description of the CCD method. A construction similar to that given in Lemma 3-8 for the normal CD method may also be used for the CCD method. This is described in the following lemma.

Lemma 4-7. [Construction of PC-conjugate set of N-vectors $\{p^i\}_{i=0}^{Q-1}$ from a Complete Orthogonal Set $\{q^i\}_{i=0}^{N-1}$]

Let $\{q^i\}_{i=0}^{N-1}$ be a complete orthogonal basis of the projected space PC^N , i.e.,

$$PC^{N} = \left\{ \underline{v} : \underline{v} = \sum_{i=0}^{N-1} a_{i}\underline{p}^{i}, \underline{q}^{i} = \underline{P}\underline{q}^{i}, \forall a^{i} \in C^{1}, i \in [0, N-1] \right\}$$
 (4-33)

Then, a set of Q linearly independent PC-conjugate vectors $\begin{cases} p^i \\ i=0 \end{cases}$ may be defined as follows. The first vector is arbitrarily defined by

$$p^0 = q^{k_0} \tag{4.34}$$

where $k_0 = \min[0, N-1] \ni PC\underline{p}^0 \neq \underline{0}$. The general such vector is given by

$$\underline{p}^{i} = \underline{q}^{k_{i}} + \sum_{j=0}^{i-1} \beta_{i,j} \underline{p}^{j}$$
 (4-35)

where

$$\beta_{i,j} = \frac{(q^{i_1}, PCp^{j})^*}{(p^{j}, Cp^{j})}$$
 (4-36)

and $\{k_i\}$ is a subsequence of indices in the range [0,N-1] while i and j range over [0,Q-1] and [0,Q-2], respectively, with i > j. Futhermore, Q < R = rank C.

<u>Proof:</u> Except for the PC-conjugacy condition, the proof is identical to that of Theorem 4-6.

Variations c the construction given above are possible. For example, the orthogon lity restriction on $\{q^i\}_{i=0}^{N-1}$ could be removed. In fact, it would suffice if this set of vectors span the projected space PC^N . Furthermore, it is possible to derive the unique minimum-norm solution using the CCD method if $\underline{w}^0 \in PC^R$, the projected eigenspace of C. This, of course, follows directly from (4-14).

4.2.2 Constrained CG (CCG) Method

The derivation of the CCG method follows as a special case of the CCD method, where the orthogonal basis vectors are the successive projected gradients $\{\underline{r}^i\}_{i=0}^{Q-1}$. The conventional version of the CCG method is as stated in the following theorem.

Theorem 4-8. [Conventional Form of the CCG Method]

Consider the system

$$P(\underline{Cw} + \underline{b}) = \underline{0} \tag{4-37.1}$$

$$(\underline{\mathbf{e}},\underline{\mathbf{w}}) = \mathbf{d} \tag{4-37.2}$$

• :

where C is an N x N complex Hermitian matrix of rank R, \underline{b} is a complex N-vector contained in C^R , the eigenspace of C, \underline{e} is a complex constraining N-vector, d is a real-valued scalar, P is a complex N x N unitary matrix

$$P = I - \frac{e e^{\frac{AT}{2}}}{\|\underline{e}\|^2}$$
 (4-38)

the projection generator that produces ti. projection of any vector $\underline{\mathbf{y}} \in \mathcal{C}^{N}$ onto the hyperplane (4-37.2) and $\underline{\mathbf{w}}$ is the complex N-vector to be determined.

The general solution to (4-37) is the last iterate, \underline{w}^{Q-1} , of a Q-step iterative procedure that begins with an initial solution estimate, $\underline{w} \in PC^N$, the corresponding projected residual, $\underline{r}^0 = P(C\underline{w}^0 + \underline{b})$, and, upon setting $\underline{p}^0 = \underline{r}^0$, repeats relations

$$\alpha_{i} = \frac{\|\underline{r}^{i}\|^{2}}{(\underline{r}^{i}, rc\underline{r}^{i})}$$
 (4-39.1)

$$\underline{\underline{w}}^{i+1} = \underline{\underline{w}}^i - \alpha_i \underline{\underline{P}}^i$$
 (4.375.27)

$$\underline{\mathbf{r}^{i+1}} = \underline{\mathbf{r}^{i}} - \mathbf{a}_{i} \mathbf{P} \mathbf{c} \underline{\mathbf{r}^{i}}$$
 (4.30.)

$$\beta_{i} = \frac{\|\mathbf{r}^{i+1}\|^{2}}{\|\mathbf{r}^{i}\|^{2}}$$
 (3.25).

$$\underline{\mathbf{g}}^{\mathbf{i}+1} = \underline{\mathbf{r}}^{\mathbf{i}+1} + \beta_{\mathbf{i}}\underline{\mathbf{f}}^{\mathbf{i}} \qquad \qquad -\infty.5)$$

for $i=0,1,\ldots,Q-1$. This procedure is referred to as the <u>conventional</u> form of the constrained conjugate gradients (CCG) method.

<u>Proof:</u> Except for using Lemma 4-5, Theorem 4-6 and the EC-coniugacy condition, result (4-39) follows the same arguments in the proof of Theorem 3-9.

The standard and alternate forms of the CCG method differ from the conventional form only in the definition of expansion coefficients; that is,

$$\alpha_{i} = \frac{(\underline{p}^{i},\underline{r}^{0})}{(\underline{p}^{i},PC\underline{p}^{i})}$$
 (.40)

for the standard CCG method, and

$$\alpha_{i} = \frac{(\underline{z}^{i},\underline{r}^{i})}{(\underline{r}^{i},\text{POr}^{i})}$$

for the alternate CCG method.

As in the case of the unconstrained CG method, the CCG method is a descent, or relaxation method. Figure 4-2 attempts to heuristically demonstrate the geometrical interpretation of the CCG method. Noted there is the unconstrained solution, $\hat{\mathbf{w}}$, location in the geometrical center of a continuum of concentric ellipsoidal contours of equal combined powers. For this 3-dimensional system, it is shown that the CCG process begins at an initial estimate on the constraining hyperplane and undergoes a relaxation there in two steps to the final constrained solution, $\hat{\mathbf{w}}^{\mathbf{c}}$, along appropriate PC-conjugate vectors. Significantly, the CCG process is shown to converge in two and not three iterations. This is as it should be, since the constrained minimum sought lies in the geometrical center of the elliptical contours resulting from the intersection of the hyperplane with the ellipsoidal contours. Clearly, a degree of freedom has been lost by imposing the equality constraint (4-44.2).

It should be noted here that in computing the projection of any vector $\mathbf{v} \in \mathcal{C}^N$ onto the hyperplane via $\underline{P}\underline{\mathbf{v}}$, it is advisable to perform this efficiently as follows.

$$P\underline{v} = \left(I - \frac{\underline{e} \ \underline{e}}{\|\underline{e}\|^2}\right)\underline{v}$$

$$= \underline{v} - \frac{\underline{e}}{\|\underline{e}\|^2} (\underline{e},\underline{v})$$
(4-42)

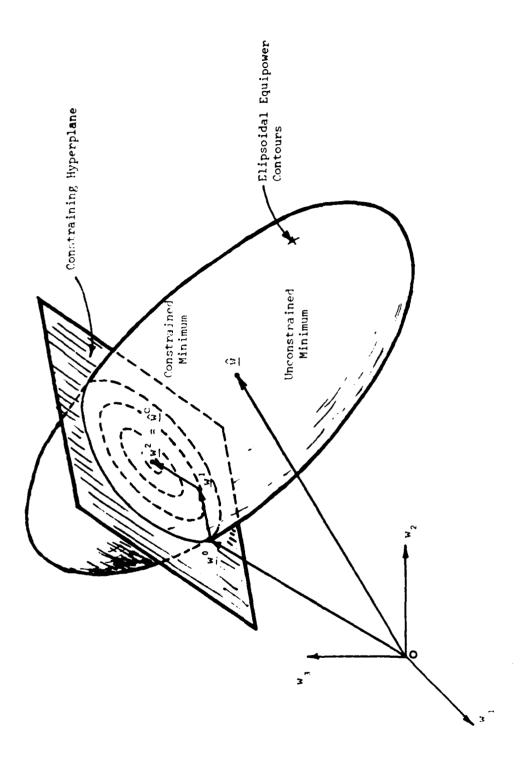
thus avoiding the need to store or perform a matrix operation with P.

This will directly effect the efficiency of computing PCp (in (4-39.1). Alternatively, one may precompute PC initially if C need not be preserved for any other reason.

Finally, noting that in (4-39.2) $p^i \in PC^R$, a choice of initial solution estimate $\underline{w}^0 \in PC^R$ will guarantee that $\hat{w}c = \underline{w}Q^{-1} \in PC^R$, and thus be the unique minimum-norm solution. As an example, an appropriate initial solution estimate is $\underline{w}^0 = \underline{de}/||\underline{e}||^2$.

4.3 Illustrative Examples

Two examples will be presented to demonstrate the validity of the closed-form Lagrange-multiplier method and the iterative CCG alternative. The examples are identical to those of Section 3.3, except for the use of an appropriate equality constraint in each case. Of particular significance is the second example which involves a singular covariance matrix. Although an approximate regularized constrained solution is possible in this case, a pseudoinverse approach does not make sense. In contrast, the CCG solution is the exact constrained solution.



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4.3.1 Full-Rank Covariance Case

 $\hbox{ \c Consider solving the linear equality-constraint minimization problem }$

$$\min_{\mathbf{W}} J(\underline{\mathbf{w}}) \tag{4-43.1}$$

$$(\underline{\mathbf{e}},\underline{\mathbf{w}}) = \mathbf{d} \tag{4-43.2}$$

where,

$$J(\underline{w}) = ||\underline{A}\underline{w} + \underline{a}||^{2}$$

$$A = \begin{pmatrix} 1 & j \\ 1 & 1 \end{pmatrix}$$

$$\underline{a} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

$$\underline{e} = \begin{pmatrix} j \\ 1 \end{pmatrix}$$

$$d = 1$$

$$(4-44)$$

Note that (4-44) is the performance index used in the example presented in Section 3.3.1. Already computed there are

$$C = A^{*T}A$$

$$= \begin{pmatrix} 2 & 1+j \\ 1-j & 2 \end{pmatrix} \qquad (4-46.1)$$

$$b = A^{*T} \underline{a} + f$$

$$= \begin{pmatrix} 1 \\ -i \end{pmatrix} \qquad (4-46.2)$$

We will solve for $\hat{\underline{w}}^C$ by the Lagrange-multiplier method of Theorem 4-1 and by the CCG method of Theorem 4-4.

Lagrange-Multiplier Solution:

By Theorem 4-1.

$$\frac{\hat{\mathbf{w}}^{\mathsf{C}}}{\mathbf{e}} = \frac{\hat{\mathbf{w}}}{\mathbf{e}} - \lambda \mathbf{C}^{-1} \underline{\mathbf{e}} \tag{4-47}$$

where

$$\frac{\hat{w}}{2} = -C^{-1}\underline{b}$$

$$= -\frac{1+j}{2} \binom{1}{-1}$$
(4-48)

is the unconstrained solution already computed in (3-94). Also,

$$(\underline{e}, \hat{\underline{w}}) = -\frac{1+j}{2} \begin{pmatrix} -j \\ 1 \end{pmatrix}^{T} \begin{pmatrix} 1 \\ -1 \end{pmatrix}$$

$$= \frac{(1+j)^{2}}{2}$$

$$= j \qquad (4-49)$$

and, using, C^{-1} from (3-93),

$$C^{-1}\underline{e} = \frac{1}{2} \begin{pmatrix} 2 & -(1+j) \\ -(1-j) & 2 \end{pmatrix} \begin{pmatrix} j \\ 1 \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} -1+j \\ 1-j \end{pmatrix}$$

$$= \frac{1-j}{2} \begin{pmatrix} -1 \\ 1 \end{pmatrix} \qquad (4-50)$$

$$(\underline{\mathbf{e}}, \mathbf{c}^{-1}\underline{\mathbf{e}}) = \frac{1-\mathbf{j}}{2} \begin{pmatrix} -\mathbf{j} \\ 1 \end{pmatrix}^{\mathrm{T}} \begin{pmatrix} -1 \\ 1 \end{pmatrix}$$
$$= \frac{(1-\mathbf{j})(1+\mathbf{j})}{2}$$
$$= 1 \tag{4-51}$$

By (4-5.2), the complex composite Lagrange multiplier is

$$\lambda = -\frac{d - (\underline{e}, \underline{\alpha})}{(\underline{e}, c^{-1}\underline{e})}$$

$$= - (1-j) \qquad (4-52)$$

Then, using (4-47), the desired constrained solution is

$$\frac{\hat{\mathbf{g}}^{c}}{=} = \frac{\hat{\mathbf{g}} - \lambda c^{-1} \underline{\mathbf{e}}}$$

$$= -\frac{1+j}{2} \binom{1}{-1} + \frac{(1-j)^{2}}{2} \binom{-1}{1}$$

$$= -\frac{1}{2} \binom{1+j}{-1-j} - \frac{1}{2} \binom{-2j}{2j}$$

$$= -\frac{1}{2} \binom{1-j}{-1+j}$$

$$= -\frac{1-j}{2} \binom{1}{-1}$$
(4-53)

The validity of (4-53) may now be checked. Given that d=1, we note that $\underline{\Theta}^{C}$ satisfies constraint (4-43.2); i.e.,

$$(\underline{e}, \hat{\underline{w}}^{c}) = -\frac{1-j}{2} \begin{pmatrix} -j \\ 1 \end{pmatrix}^{T} \begin{pmatrix} 1 \\ -1 \end{pmatrix}$$

$$=\frac{(1-j)(1+j)}{2}$$

(4-54)

We need to check whether the projected gradient

$$P\nabla_{\underline{W}}J(\underline{w}) = P(\underline{Cw} + \underline{b}) \tag{4-55}$$

vanishes at $\hat{\underline{w}}^{c}$. By (4-46) and (4-53),

$$\frac{C\hat{w}^{c}}{2} + \underline{b} = -\frac{1-j}{2} \begin{pmatrix} 2 & 1+j \\ 1-j & 2 \end{pmatrix} \begin{pmatrix} 1 \\ -1 \end{pmatrix} + \begin{pmatrix} 1 \\ -j \end{pmatrix}$$

$$= -\frac{(1-j)}{2} \begin{pmatrix} 1-j \\ -1-j \end{pmatrix} + \begin{pmatrix} 1 \\ -j \end{pmatrix}$$

$$= -\frac{1}{2} \begin{pmatrix} -2j \\ -2 \end{pmatrix} + \begin{pmatrix} 1 \\ -j \end{pmatrix}$$

$$= \begin{pmatrix} j \\ 1 \end{pmatrix} + \begin{pmatrix} 1 \\ -j \end{pmatrix}$$

$$= \begin{pmatrix} 1+j \\ 1-j \end{pmatrix}$$

$$(4-56)$$

Then, by (4-42) and (4-45)

$$P(C\underline{\widehat{\omega}}^{C} + \underline{b}) = P\begin{pmatrix} 1+j \\ 1-j \end{pmatrix}$$

$$= \begin{pmatrix} 1+j \\ 1-j \end{pmatrix} - \frac{1}{2} \begin{pmatrix} j \\ 1 \end{pmatrix} \left[\begin{pmatrix} -j \\ 1 \end{pmatrix}^{T} \begin{pmatrix} 1+j \\ 1-j \end{pmatrix} \right]$$

$$= {1+j \choose 1-j} - (1-j) {j \choose 1}$$

$$= 0 \qquad (4-57)$$

As a consequence of (4-57) and (4-54), we have verified that (4-53) is, in fact, the correct constrained solution.

CCG Solution:

We will use Theorem 4-8 to solve (4-43), or, equivalently,

$$P(Cw + b) = 0$$
 (4-58.1)

$$(e,w) = d$$
 (4-58-2)

We choose an <u>initial solution estimate</u> that satisfies constraint (4-43.2); i.e.,

$$\frac{\mathbf{w}^0}{\mathbf{v}^0} = \frac{\mathbf{d}}{\|\mathbf{e}\|^2} = \frac{1}{2} \begin{pmatrix} \mathbf{j} \\ \mathbf{j} \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} \mathbf{j} \\ \mathbf{j} \end{pmatrix}$$
(4-59)

with corresponding projected gradient

$$\mathbf{r}^{0} = P(\underline{C}\underline{w}^{0} + \underline{b})$$

$$= P\left[\frac{1}{2}\begin{pmatrix} 2 & 1+j \\ 1-j & 2 \end{pmatrix} \begin{pmatrix} j \\ 1 \end{pmatrix} + \begin{pmatrix} 1 \\ -j \end{pmatrix}\right]$$

$$= P\left[\frac{1}{2}\begin{pmatrix} 1+3j \\ 3+j \end{pmatrix} + \begin{pmatrix} 1 \\ -j \end{pmatrix}\right]$$

$$= P\left[\frac{1}{2}\binom{3+3j}{3-j}\right]$$

$$= \frac{1}{2}\binom{3+3j}{3-j} - \frac{1}{4}\binom{j}{1}\left[\binom{-j}{1}^{T}\binom{3+3j}{3-j}\right]$$

$$= \frac{1}{2}\binom{3+3j}{3-j} - \frac{3-2j}{2}\binom{j}{1}$$

$$= \frac{1}{2}\binom{1}{j}$$
(4-60)

where we have used (4-42). Note that \underline{r}^0 is parallel to the hyperplane defined by (4-58.2). In fact,

$$(\underline{\mathbf{e}},\underline{\mathbf{r}}^{\mathfrak{d}}) = \frac{1}{2} \begin{pmatrix} -\mathbf{j} \\ 1 \end{pmatrix}^{\mathsf{T}} \begin{pmatrix} 1 \\ \mathbf{j} \end{pmatrix} = 0 \tag{4-61}$$

Setting $p^0 = r^0$, we follow procedure (4-39).

$$\left\| \underline{r}^{0} \right\|^{2} = \frac{1}{2}$$
 (4-62)

$$c_{\mathbf{p}^{0}} = \frac{1}{2} \begin{pmatrix} 2 & 1+j \\ 1-j & 2 \end{pmatrix} \begin{pmatrix} 1 \\ j \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} 1+j \\ 1+j \end{pmatrix}$$

$$= \frac{1+j}{2} \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$
(4-63)

$$PC\underline{p}^{0} = \frac{1+j}{2} \binom{1}{1} - \frac{1}{2} \left[\frac{1+j}{2} \binom{-j}{1}^{T} \binom{1}{1} \right] \binom{j}{1}$$

$$= \frac{1+j}{2} \binom{1}{1} - \frac{1}{2} \binom{j}{1}$$

$$= \frac{1}{2} \binom{1}{j} \qquad (4-64)$$

where we have used (4-42). Note again that PCp^0 is in the hyperplane (4-58.2). Continuing,

$$(\underline{p}^{0}, PC\underline{p}^{0}) = \frac{1}{4} {1 \choose -j}^{T} {1 \choose j}$$

$$= \frac{1}{2}$$
(4-65)

$$\alpha_{0} = \frac{||\underline{r}^{0}||^{2}}{(\underline{p}^{0}, PC\underline{p}^{0})}$$

$$= 1 \qquad (4-66)$$

$$\underline{w}^{1} = \underline{w}^{0} - \alpha_{0}\underline{p}^{0}$$

$$= \frac{1}{2} \begin{pmatrix} \mathbf{j} \\ 1 \end{pmatrix} - \frac{1}{2} \begin{pmatrix} 1 \\ \mathbf{j} \end{pmatrix}$$

$$= \frac{-1}{2} \begin{pmatrix} 1 - \mathbf{j} \\ -1 + \mathbf{j} \end{pmatrix}$$

$$= -\frac{1 - \mathbf{j}}{2} \begin{pmatrix} 1 \\ -1 \end{pmatrix}$$
(4-67)

$$\mathbf{r}^{1} = \underline{\mathbf{r}}^{0} - \alpha_{0} P C \underline{\mathbf{p}}^{0}$$

$$= \frac{1}{2} \binom{1}{j} - \frac{1}{2} \binom{1}{j}$$

$$= \underline{0} \tag{4-68}$$

Since $\|\underline{r}^1\| = 0$, the process terminates here. Then,

$$\underline{\mathbf{w}}^{1} = \hat{\underline{\mathbf{w}}}^{\mathbf{C}} \tag{4-69}$$

which agrees with the Lagrange-multiplier solution, (4-53).

It should be noted here that, whereas the unconstrained solution, $\underline{\hat{w}}$, takes 2 CG iterations, the CCG process required only 1 to produce the constrained solution $\underline{\hat{w}}^{\text{C}}$. This is as expected and demonstrated in Figure 4-1.

4.3.2 Singular Covariance Case

Consider solving the singular linear equality-constraint minimization problem

$$\begin{array}{ll}
\min \ J(\underline{w}) \\
\underline{w}
\end{array} (4-70.1)$$

$$(\underline{\mathbf{e}},\underline{\mathbf{w}}) = \mathbf{d} \tag{4-70.2}$$

where,

$$J(\underline{w}) = \|\underline{A}\underline{w} + \underline{a}\|^{2}$$

$$A = \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}$$

$$\underline{a} = \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

$$\underline{\mathbf{e}} = \begin{pmatrix} 1 \\ -1 \end{pmatrix}$$

Note that $J(\underline{w})$ is the performance index used in the example presented in Section 3.3.2. Alr ly computed there are

d = 1

$$C = A^{*T}A$$

$$= 2\begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}$$
(4-73.1)

(4-72)

$$\underline{b} = 2 \begin{pmatrix} 1 \\ 1 \end{pmatrix} \tag{4-73.2}$$

where C is, clearly, singular.

We will solve for $\underline{\hat{w}}^{C}$ by the Lagrange-multiplier method of Theorem 4-1 using the approximate regularized inverse, C^{-1} , of C. Subsequently, we will examine the Lagrange multiplier solution using the pseudoinverse, C^{+} , of C. Finally, we will solve for $\underline{\hat{w}}^{C}$ via the CCG method of Theorem 4-4.

Regularized Inversion Solution:

By regularizing C to \tilde{C} via (2-21), we may insure the existence of an approximate inverse, \tilde{C}^{-1} , which we will use here. Then, by Theorem 4-1

$$\underline{\widetilde{\mathbf{w}}}^{\mathbf{C}} = \underline{\widetilde{\mathbf{w}}} - \lambda \widetilde{\mathbf{C}}^{-1} \underline{\mathbf{e}} \tag{4-74}$$

where \tilde{w}^{c} is the regularized constrained solution, and

$$\frac{\tilde{\mathbf{w}}}{\tilde{\mathbf{w}}} = -\tilde{\mathbf{c}}^{-1}\underline{\mathbf{b}}$$

$$= -\frac{1}{(2+\epsilon)} \begin{pmatrix} 1\\1 \end{pmatrix}$$
(4-75)

is the unconstrained regularized solution already computed in (3-124). Also,



$$(\underline{e}, \widetilde{\underline{w}}) = 0 \tag{4-76}$$

and, by (3-123),

$$\tilde{c}^{-1}\underline{e} = \frac{1}{2(2+\epsilon)} \begin{pmatrix} 2+\epsilon \\ -(2+\epsilon) \end{pmatrix}$$

$$= \frac{1}{2\epsilon} \begin{pmatrix} 1 \\ -1 \end{pmatrix} \qquad (4-77)$$

$$(\underline{\mathbf{e}}, \mathbf{\tilde{c}}^{-1}\mathbf{e}) = \frac{1}{\varepsilon} \tag{4-78}$$

By (4-5.2), the complex composite Lagrange multiplier is

$$\lambda = -\frac{\tilde{d}^{1} - (\underline{e}, \underline{\tilde{w}})}{(\underline{e}, \tilde{c}^{-1}\underline{e})}$$

$$= -\varepsilon \qquad (4-79)$$

Then, using (4-74), the desired regularized constrained solution is

$$\frac{\tilde{w}^{c}}{\tilde{u}^{c}} = \frac{\tilde{w}}{\tilde{u}} - \lambda \tilde{c}^{-1}\underline{e}$$

$$= -\frac{1}{(2+\epsilon)} \binom{1}{1} + \frac{1}{2} \binom{1}{-1}$$

$$= \frac{1}{2(2+\epsilon)} \binom{2+\epsilon-2}{-2-\epsilon-2}$$

$$= \frac{1}{2(2+\epsilon)} \binom{\epsilon}{-4-\epsilon}$$
(4-80)

The validity of (4-80) may now be checked. Given that d=1, we note that w^{c} satisfies constraint (4-70.2); i.e.,

$$(\underline{e}, \underline{\tilde{w}}) = \frac{1}{2(2+\varepsilon)} \begin{pmatrix} \varepsilon \\ -4-\varepsilon \end{pmatrix}^{T} \begin{pmatrix} 1 \\ -1 \end{pmatrix}$$

$$= \frac{4+2\varepsilon}{2(2+\varepsilon)}$$

$$= 1 \qquad (4-81)$$

We need to check that the regularized projected gradient

$$P\nabla_{\underline{w}}J(\underline{w}) = P(\underline{c}\underline{w} + \underline{b})$$
 (4-82)

vanishes at $\frac{\tilde{w}^C}{\tilde{w}^C}$. By (4-73) and (4-80), the <u>regularized unconstrained</u> gradient at $\frac{\tilde{w}^C}{\tilde{w}^C}$ is

$$= \frac{1}{(2+\epsilon)} {\begin{pmatrix} 1+\epsilon & 1 \\ 1 & 1+\epsilon \end{pmatrix}} {\begin{pmatrix} \epsilon \\ -4-\epsilon \end{pmatrix}} 2 {\begin{pmatrix} 1 \\ 1 \end{pmatrix}}$$

$$= \frac{1}{(2+\epsilon)} {\begin{pmatrix} \epsilon(1+\epsilon) - (4+\epsilon) \\ \epsilon - (1+\epsilon)(4+\epsilon) \end{pmatrix}} + 2 {\begin{pmatrix} 1 \\ 1 \end{pmatrix}}$$

$$= \frac{1}{(2+\epsilon)} {\begin{pmatrix} \epsilon^2 + \epsilon - \epsilon - 4 + 4 + 2\epsilon \\ \epsilon - \epsilon^2 - 5\epsilon - 4 + 4 + 2\epsilon \end{pmatrix}}$$

$$= \frac{1}{(2+\epsilon)} {\begin{pmatrix} \epsilon^2 + 2\epsilon \\ -\epsilon^2 - 2\epsilon \end{pmatrix}}$$

$$= \epsilon {\begin{pmatrix} 1 \\ -1 \end{pmatrix}} (4-83)$$

clearly colinear to <u>e</u>, or, equivalently, normal to hyperplane (4-70.2). Hence, its projection, (4-82), must vanish. Consequently, (4-80) is the correct regularized constrained solution.

Pseudoinversion Solution:

At this point one may naturally inquire as to whether it makes sense to use the pseudoinverse, C^{\dagger} , in the Lagrange-multiplier solution of Theorem 4-1. That is,

$$\underline{\alpha}^{c} = \underline{\alpha} - \lambda C^{\dagger}\underline{e} \tag{4-84}$$

where

$$\frac{\mathcal{Q}}{2} = -c^{\dagger}\underline{b}$$

$$= -\frac{1}{2}\binom{1}{1}$$
(4-85)

is the <u>unconstrained minimum-norm solution</u> already computed in (3-130). Since

$$C^{\dagger}\underline{e} = \underline{0} \tag{4-86}$$

 $(\underline{e}, C^{\dagger}\underline{e}) = 0$, so that λ is not well defined by (4-5.2). Hence, (4-84) does not make sense. This simple example demonstrates that, in general, the pseudoinverse may not be used to derive the desired Lagrange multiplier solution.

CCG Solution:

We will use Theorem 4-8 to solve (4-70). As in the previous example, we choose as <u>initial</u> solution estimate

$$\underline{w}^{0} = \frac{d}{\|\underline{e}\|^{2}} \underline{e}$$

$$= \frac{1}{2} \begin{pmatrix} 1 \\ -1 \end{pmatrix}$$
(4-87)

with corresponding initial projected gradient

$$\underline{\underline{r}}^{0} = P(\underline{\underline{cw}}^{0} + \underline{\underline{b}})$$

$$= P\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} 1 \\ -1 \end{pmatrix} + 2 \begin{pmatrix} 1 \\ 1 \end{pmatrix} \end{bmatrix}$$

$$= P\begin{bmatrix} 2 \begin{pmatrix} 1 \\ 1 \end{pmatrix} \end{bmatrix}$$

$$= 2 \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

$$(4-88)$$

which follows directly, since $(1 \ 1)^T$ is normal to \underline{e} . Setting $\underline{p}^0 = \underline{r}^0$, we follow procedure (4-39)

$$\left\|\underline{r}^{0}\right\|^{2} = 8 \tag{4-89}$$

$$C\underline{p}^0 = 4 \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

$$= 8 \binom{1}{1} \tag{4-90}$$

$$PC\underline{p}^{0} = 8 \begin{pmatrix} 1 \\ 1 \end{pmatrix} \tag{4-91}$$

$$(\underline{p}^0, PC\underline{p}^0) = 32$$
 (3-92)

$$\alpha^0 = \frac{1}{4} \tag{4-93}$$

$$\underline{w}^{1} = \underline{w}^{0} - \alpha_{0} \underline{p}^{0}$$

$$= \frac{1}{2} \begin{pmatrix} 1 \\ -1 \end{pmatrix} - \frac{2}{4} \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

$$= \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$
(4-94)

Noting that

$$\underline{\mathbf{r}}^{1} = P(\underline{\mathbf{C}}\underline{\mathbf{w}}^{1} + \underline{\mathbf{b}})$$

$$= P \left[2 \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} 0 \\ -1 \end{pmatrix} + 2 \begin{pmatrix} 1 \\ 1 \end{pmatrix} \right]$$

$$= \underline{P0}$$

$$= \underline{0}$$

$$(4-95)$$

the CCG process terminates. The desired solution is thus

$$\underline{\hat{w}}^{C} = \underline{w}^{1} = \begin{pmatrix} 0 \\ -1 \end{pmatrix} \tag{4-96}$$

It is interesting to note here that solution (4-96) is the constrained minimum-norm solution which happens to be the limit of the constrained regularized solution (4-80) as $\varepsilon \rightarrow 0$.

5.0 CONCLUDING REMARKS

The present memorandum has described the concept of <u>Batch</u>
Covariance Relaxation (BCR) adaptive processing in the context of a
baseband digitally-implementable sidelobe cancellation subsystem. Based
on the numerically-stable and computationally-efficient <u>conjugate</u>
gradients (CG) method, the BCR process constitutes an attractive
alternative to conventional inversion approach particularly in large-scale
applications. A variation of the BCR process has been introduced which
addresses effectively the more general constrained adaptive array problem
which includes the special case of adaptive beamforming.

More specifically, the memorandum begins by contrasting batch adaptive processing to dynamic processing, in general. Whereas the typical dynamic adaptive process exhibits an undesired transience to a nonstationary interference environment, a batch process is designed to circumvent this vulnerability.

With reference to adaptive array processing, the mathematical formulation of the batch adaptive process, based on a minimum-mean-square (MMS) criterion, leads to the special linear system

$$C\underline{w} + \underline{b} = \underline{0} \tag{5-1}$$

where C is a complex N x N Hermitian matrix, \underline{b} is a complex N-vector in the eigenspace of C, and \underline{w} is the unknown complex N-vector to be determined.

The conventional Sample Matrix Inversion (SMI) solution to (5-1) depends on the existence of the matrix inverse, C-1. When C-1 does not exist, C may be regularized by adding to it a sufficient amount of additive diagonal variance, thereby guaranteeing the existence of an approximate inverse, Č-1, the regularized inverse of C. In so doing, the regularized inversion solution will incur an error and thus will not satisfy (5-1) exactly. Using the SVD method, however, it is possible to construct an inverse operator, C+, the pseudoinverse of C, which may be used to derive the unique minimum-norm solution. Even so, with increasing system dimensionality, "open-loop" inversion approaches become numerically more and more sensitive, require comparatively greater computational precision and eventually reach a point where they are operationally unreliable.

The BCR approach offers a practical alternative to solving (5-1) without the need for explicit inversion of C. The general conjugate directions (CD) method begins with an arbitrary initial solution estimate, \underline{w}^0 , and subsequently produces a sequence of improved estimates, \underline{w}^1 , \underline{w}^2 , ..., along specific relaxation directions, such that \underline{w}^0 is the minimumnorm solution to (5-1) and Q does not exceed the system dimensionality N. From the numerical point of view, the iterative nature of the CD

process may be exploited to minimize roundoff error. Replacing \underline{w}^0 by \underline{w}^Q , the CD process may be executed a second time thereby refining the solution. This is a particularly useful mechanism for guaranteeing reliable numerical performance in practical large-scale applications.

The conjugate gradients (CG) method is a computationally-efficient special case of the general CD method. As a consequence, it is the recommended relaxation procedure for BCR processing.

A detailed mathematical development of the CD and CG methods is followed by two illustrative numerical examples which serve to demonstrate their special properties in direct contrast to appropriate inversion solutions.

The more general equality-constraint adaptive problem is considered next. A conventional Lagrange-multiplier solution to this problem is first derived. Subsequently, motivated by geometrical considerations, the BCR process is extended to apply effectively to this problem. The constrained CG (CCG) method follows directly from a detailed development of the general constrained CD (CCD) method. Two simple numerical examples are included to demonstrate the validity of the CCG method and to contrast it to the closed-form Lagrange-multiplier method which requires an explicit inverse of C. The second example which involves a singular matrix C is particularly interesting. Although a regularized inversion approach is useful for deriving an approximate Lagrange-multiplier solution, it is shown that a pseudoinverse cannot be used. In contrast, the CCG approach remains valid in this case.

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COMPUTER SIMULATION OF BCR ADAPTIVE PROCESS

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1.0 INTRODUCTION

The present memorandum presents the modular analytical software developed for the purpose of analyzing the adaptive nulling performance of an adaptive array system employing the BCR adaptive process.

As stated previously, the system considered involves a Taylor-weighted main linear antenna array in combination with a set of weighted omnidirectional auxiliaries for the purpose of nulling a number of noise sources incident in the sidelobe region of the main antenna pattern. The adaptive weight adjustment is accomplished at baseband using the Batch Covariance Relaxation (BCR) approach.

The first section that follows discusses the general library-based software approach adopted for the analysis, employing the FORTRAN language. Included there is a detailed description of three major modular programs developed for the purpose. The first is SIGGEN, the latest version of the Signal Generation Program previously presented in Project Memorandum 8512-02. The second is BCRS, the BCR Simulation Program. The third is BCRP, the BCR Performance and Plotting Program.

The SIGGEN program utilizes system and scenario information from an input data file, SIGGEN:D, and produces an output data file, SIGGEN:O, containing sampled complex baseband signals received at the main and auxiliary ports specified. The input data file is written in the form of a menu that is flexible enough to allow a user to easily construct a case of interest by choosing RF bandwidth, single and multitap weighting, independent or multipath sources, etc.

Attaching SIGGEN:O to a small BCR header file, BCRS:DO, forms the input data file, BCRS:D, for the BCRS program. The BCRS program uses the port signal data in BCRS:D, exercises the BCR algorithm, produces the adaptive auxiliary weights and applies them on the port signals to produce the desired low-noise combined signal. Data produced by BCRS is transferred to output file, BCRS:O.

The input data file, BCRP:D, for program BCRP is formed by editing BCRS:O. Specifically, the actual number of iterations indicated in BCRS:O is entered in a reserved location of the header file, BCRS:DO, marked with an "X". Then all output between the end of the main-port signal and the beginning of the combined signal is deleted, except for the so-called composite weight-vector array. This augmentation procedure will become clear in the following section. The output from BCRP is in the form of an output file BCRP:O summarizing the BCR performance and its equivalent graphical representation via a TEKTRONIX plotting terminal.

The particular use of these three programs is explained in some detail in the next section with the aid of a benchtest example. In the subsequent section, the specific results of a number of interesting examples are presented with sufficient graphical information. Specific examples considered include a number of variations in system and scenario parameters. More general results obtained from families of related examples are also included. Finally, some comments are made on possible BCR processing alternatives.

In view of the variety of examples and general results included in this memorandum, it is clear that the software presented here constitutes a flexible and effective tool for analyzing BCR adaptive nulling performance for a specific adaptive array system in a variety of configurations and interference environments. The library-based approach used here is adaptable to analyzing even more complex and diverse adaptive systems with appropriate methodical modifications.

2.0 SIMULATION APPROACH AND PROGRAM DESCRIPTION

Discussed in this section is the structurally efficient and flexible computer simulation approach adopted for the evaluation of the BCR adaptive process applied to the adaptive array system described in Project Memorandum 8512-03. An introductory description of some important features of the general program structure is given in the first subsection. Each of the three subsequent subsections provides detailed descriptions of the structure and use of SIGGEN, BCRS and BCRP, the signal generation, BCR simulation and BCR performance and plotting programs, respectively.

2.1 General Program Structure

The three specific programs described in the next three sections share a common modular design and possess similar usage features. By way of introduction, the present section describes several of these common characteristics in the same order that the actual program details are presented subsequently.

2.1.1 Input Data File

The form of the input data file for these programs was designed with emphasis on clarity of presentation and ease of handling. The simple recurring format, used throughout the data file, clearly ties the input parameter description to its value. For a dynamic and versatile input process, key parameters are used to control the input of subsequent and related parameters. The structure of the data allows the user to focus on the important aspects of the problem description. Looking further at the details, the current system characteristics and the scenario become obvious. After the initial data construction, only the most simple editing tasks, such as character substitution, are required. This is possible partly through the leverage provided by the input control parameters, and partly through the use of multi-purpose parameters, both of which will be described later.

The input parameter names follow the implicit type convention of FORTRAN: If the name begins with a letter I-N, it is an integer. With the exception of the complex number POL(.), all other names represent real numbers. All the literals and special characters are treated as comments. The data are read with the following format:

TYPE	FORMAT	COLUMN WHERE DATA STARTS
Full-line comment	20A4	
Comment + integer scalar	14A4,I12	57
Comment + integer vector	14A4,4X,10I2	61
Comment + real scalar	14A4,F12.5	57
Comment + complex scalar	14A4,2X,2F10.5	59

With the exceptions of ISC, ISP, ISW and POL(.), the variable type is obvious from its name, so the appropriate format is easily chosen. There is an alignment of the least significant digit in the scalar integer, real, and complex real-part, so potential errors in formatting can be avoided. The deletion and addition of lines, and changing of control parameters requires care, since they affect the input process.

2.1.2 Program Classifications

The program-modules in Section 2 will be discussed under two general classifications. One classification is based on their function within the next higher level of modularity. The other is according to the form of their representation. Some names and phrases, used in programming, may have restricted meanings in the context of this section. For this reason their definition will precede the ensuing discussion.

A <u>program</u> is a complete set of instructions which can be executed by a machine. It may require input data. It consists of one or more subprograms. The most important features of a program are completeness and executability.

A <u>subprogram</u> is a main-program or a set of one or more subroutines or functions. It is not executable because it is not complete. It depends on other subprograms to complete its control structure, and it may have external references.

A <u>main-program</u> is a program, if it is executable. Otherwise, it is a subprogram.

A <u>module</u> is a unit of program structure, which spans the programsubprogram boundaries. It may be equivalent to a subroutine, subprogram, or one or more programs. A module implies portability, or an ability to facilitate grouping or separation.

The informal classification of program-modules based on their function within the next higher level of modularity is used in program description. Three categories are identified.

An $\underline{\text{executive}}$ subprogram does little or no calculation, but calls other subprograms to do so.

A <u>dedicated</u> subprogram is devoted to performing tasks related to specific subjects. An example of this is the subroutine which computes the antenna weighting function, ANTWT. Although they can be called by more than one subprogram, their output will always be specifically dedicated to the same subject.

A general or utility subprogram performs the same task whenever called, but the subject of the task is general. Examples are the random number generator and FFT routines, as well as the input/output subprograms like RW and RWIRC.

A more formal classification is applied to the creation and subsequent execution of programs. It concerns the form of the program-modules, or how they are physically represented as file types.

A source module is a type of file which is created by the programmer, written in $\overline{\text{FORTRAN}}$.

A <u>binary</u> or <u>object</u> module is created by a compiler. It constitutes a translation of the source program-module. Thus there is a one-to-one correspondence between a source module and its binary version. These modules are referenced and made available by a programmer, but they need not be edited or read.

The executable <u>load</u> module is created when all the binary modules which refer to one-another are linked together in such a way that they form a counterpart of the complete, executable source program. This type of file can be directly executed by the machine when appropriate input data is made available.

The naming convention (established for this project) makes use of a suffix to distinguish these and other file types. The following list defines some of these suffixes.

SUFFIX	MODULE FILE TYPE
: S	source
:B	binary
:L	load
:D	data-input
:0	data-output

It should be noted that S, B, and L suffix can be applied to the same program or subprogram, consistent with the definition and classification of "module". The suffix D and O can also be applied to the same program; however, they are not suffixes of program modules, but related to the program modules. The significance of this convention will be apparent when job control language (JCL) programs are discussed. There are other types of modules, such as a general information file, of which only one will be referenced here, and JCL types, which will be introduced later. The one information file of importance is RADAR:LIB. Its name is meant to associate a library of programs with radar signal processing. Its function is that of an index file. It shows name, author, and dates of origin and latest revision of members of the RADAR program library, which may be a subset of a larger program library. The yet unofficial rules of the library need to be pointed out here, since they have important effects on the use of the member programs.



- 1. Only programs and subprograms which meet a certain standard may become members.
- 2. Only the latest revision of a member may exist. This implies that early versions are discarded, and that there is only one program or subprogram referred to by the same name, excluding suffixes to denote type.
- Revisions and variations of members must meet requirements 1 and 2.

The RADAR:LIB information file is shown in Table 2-1.

2.1.3 Physical and Procedural Structures

In the attempt to produce efficient programs which are easy to use, understand, and maintain, certain priorities have to be established. There is always a compromise among these features, and room for improvement whenever the priorities shift.

The physical structure assigned to these programs is modular. The modules are separated by sometimes clearly defined subjects or functions, sometimes by physical or algorithmic necessities. The aim in each case is to produce modules or branches of modules in natural ways, rather than in contrived ways for the sake of "structuring".

The description of the following programs will be enhanced with the use of tree diagrams. The primary purpose of such diagrams is to show all the modules of the program, and their interrelationship. This ordered relationship is called the physical structure. The named blocks are subprograms, and the solid lines show exactly what other subprograms are needed by any subprogram. With some care, the tree diagram can also be made to convey a sense of timing related to the execution of the program, that is, to show its dynamic or procedural structure. This is possible because the modules are shown in the order in which they are first called during execution.

These program structures have no hidden complexity. They are as simple as they appear in the tree diagram. They are linear structures in the sense that adding or deleting a branch requires only a local change, no matter where the addition or deletion happens to be. This is one of the desirable features of modularity. Another important feature is the ability to change any module with confidence that other modules will not be affected by the change, as long as the local modular interface remains intact. The interface consists of common blocks or arguments passed in call statements, or both.

[†]The standard has not been specified formally.

Table 2-1. Radar Program Library, RADAR:LIB Catalog of Source and JCL Programs

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3	CMPCHNL 1S	S. M. DANIEL I. KERTESZ	8/04/80	1/30/81
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	FIELDIS	S. M. DANIEL I. KERTESZ	8/04/80	1/31/81
14	FILTERIS	S. M. DANIEL I. KERTESZ	4/19/80	6/23/80
5	FORMIS	S. M. DANIEL I. KERTESZ	4/15/78	9/13/80
H	IMPULSIS	S. M. DANIEL I. KERTESZ	5/11/80	6/07/80
5	JCL 18	S. M. DANIEL G. C. WANG	6/20/80	7/01/80
ဗ	JCLIEX	S. M. DANIEL G. C. WANG	6/22/80	6/23/80
2	JCL BCRP 1AL	S. M. DANIEL	1/06/81	18/92/2
3	JCL BCRS 1BL	S. M. DANIEL	1/06/81	2/26/81
3	JCLS IG18L	S. M. DANIEL G. C. WANG	6/21/80	2/26/81
₹	PLOTS:S	S. M. DANIEL I. KERTESZ	9/ 6/80	2/ 2/81

9/12/60	1/56/81	6/15/80	8/13/80	1/05/81	1/05/81	9/01/80	1/15/81	2/23/81	2/23/81	9/13/80
9/11/60	8/31/78	4/19/78	4/19/80	6/01/80	4/19/80	08/80/9	6/01/80	2/23/81	8/01/80	9/13/80
S. M. DANIEL I. KERTESZ	S. M. DANIEL I. KERTESZ G. C. WANG	S. M. DANIEL I. KERTESZ								
PYRSUPIS	RCNORMIS	Ruis	RWIRCIS	PRTSGNL 1S	SIGMAINIS	SIGNALIS	SIGSETIS	SKIPRIS	TTEKSIS	VITER:S
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2.1.4 Source Modules

In writing the programs, a serious attempt was made to make their use self-explanatory. Thus a short functional description, complete input and output identification and generous commentary are included with each subprogram. The heading of each module also shows the original and latest revision dates, and identities of the authors. Also, in the case of subroutines, the subroutine name is identical to the module name, except for suffixes, which are not used in the subroutine name.

2.1.5 Binary Modules

When working with a small or a fully checked out program, it is eften desirable to submit it for execution in what appears to be a one-step job. Although in reality the job may consist of compile, link, and run steps, the user is not concerned with these details provided the program runs properly. While developing a large program like SIGGEN, however, this action may not be satisfactory.

Although SIGGEN and the other programs have been through several versions, the modular structure was there from the beginning. This structure enabled the semi-independent planning, implementation of models, and refinement of the resulting modules. When a module achieved a satisfactory form, its binary version, which is the product of a compile step, was saved. Therefore, when future jobs required this module, its binary version could be used directly without needs to be edited and subsequently compiled to recreate the new binary version.

An example of the job control language program to compile a source module is shown in Table 2-2. The JCL program, JCL:B, defines a source type file

Table 2-2. JCL Program, JCL:B

1.000 !JOB 298, DANIEL (8512), 7, BLDG93

2.000 !LIMIT (TIME,1),(U0,10),(C0,16),(ACCOUNT)

3.000 !.....JCL:B.....

4.000 !SET M:SI/NAME:S;IN;SAVE

5.000 !SET M:BO/NAME:B;OUT;SAVE

6.000 !FORTRAN LS,NS,BC,SI,BO

and a binary file, and makes them available as input and output to the compiler. To submit the job, the interactive command,

!BATCH JCL:B 'NAME'=XXXX

is entered, where XXXX following the equal sign stands for the desired source module name to be used. Thus program JCL:B is general.

It should be noted that the above example and other JCL programs to be shown in the following paragraphs apply specifically to the Honeywell CP-V computer system. The purpose and the general result of these programs, however, apply to any system.

2.1.6 Load Modules

The modularity of the programs makes it possible to use the programlibrary approach. Here are three of the most obvious advantages:

- Reduction of file space because of shared member programs and subprograms.
- 2. Savings of time and effort in file manipulation, editing, and printing, because work is concentrated only on the modules affected, rather than the entire program.
- Easier to maintain because there is only one copy of each member. In case of shared subprograms, this avoids the necessity of making the same change in several places.

A load module, NAME:L, an executable version of a complete source program, NAME:S, may be formed as follows. First, the binary versions of the set of modules comprising the program are concatenated into a composite binary module, NAME:B. Subsequently, this composite binary module is copied over the load module via a LYNX command. This process is carried out via the execution of a JCL program, JCLNAME:BL, listed in Table 2-3.

Table 2-3. JCL Program, JCLNAME:BL

21124 MAR 20.181 DC/JCLNAME:BL.298

1.000	IJOB 2	298.DANI	EL(8512)•7	7•BLDG90
5.000	ILIMI'	T (TIME.	1) • (UO • 2) ((CO+16)+(ACCOUNT)
3.000	1	JCLNAME	:BL	• • • • • • • • • • • • • • • • • • • •
4.000	IPCL			
5.000	С	MAIN:B	OVER	NAMEIR
6.000	С	SUB1:B		
7.000	С	SUR2:8		
8.000	ILYNX	NAME : R	OVER	NAMEIL

This JCL program is executed with the command.

!BATCH JCLNAME:BL

Note that after such an execution all library modules are returned to the library intact.

[†]An alternate method for forming NAME:L involves a direct linking of the individual binary without the need to create a composite binary module.

2.1.7 Generic Modular Program Structure

The modular program description discussed above is summarized clearly in Figure 2-1. Demonstrated there are the ideas and steps described, from the conception of the mathematical model to the desired output. The code "NAME" is used to indicate a general program name to be substituted upon execution. As such, this figure represents a procedure that is applicable to the three major programs to be discussed next; namely, SIGGEN, BCRS and BCRP.

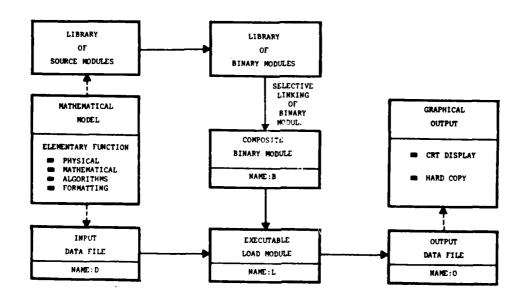


Figure 2-1. Generic Modular Program Structure

2.2 Signal Generation Program - SIGGEN

As already described in Project Memorandum 8512-02, SIGGEN is a modular program designed to generate received baseband signals at the main antenna array and specified auxiliary ports, of the adaptive array system under consideration, due to a number of incident wideband signal sources. In addition to its specific capabilities stated there, the latest version of SIGGEN included below is capable of generating baseband signals at specified port delayline taps from direct or multipath signals.

The SIGGEN program uses input file SIGGEN:D, a menu which is used to define the source scenario and system configuration. Upon execution, the output file SIGGEN:O is formed which contains sampled baseband port signals stored in complex arrays whose dimensionality is equal to the desired number of samples, limited presently to 256.

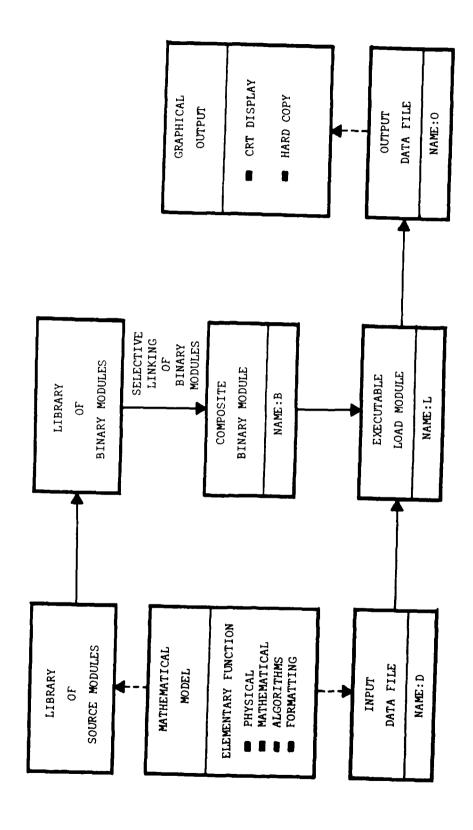


Figure 2-1. Generic Modular Program Structure

2.2.1 Input Data File - SIGGEN:D

The input data file called SIGGEN:D is listed in Table 2-4. It consists of four major parts: (1) Output control, (2) Filter, (3) Channel, and (4) Port descriptions. The first part contains the output options. These options do not affect the signal generation process; however, they can provide intermediately computed arrays for purposes of closer examination by the user. The second part of the input data file contains the description of the generic receiver in terms of its IF filter characteristics. This part, and the subsequent channel and port descriptions, completely determine the outcome of the signal general process. The third part of the data contains the channel description. An identical set of parameters is provided to describe each channel. The port parameters are included in the last part of the data file. Each port has a similar set of parameters.

A detailed description of each input parameter and the possible relationships among the parameters is indicated in Table 2-5. The parameters are listed in the same order in which they occur in the data file. This parameter description will be a useful reference for the following discussion of the benchtest scenario which is defined by the SIGGEN:D file in Table 2-4.

It can be noted that the print options are all set to the value 0, since the output controlled by them is not needed in this case.

The receiver parameters show a 2-pole filter with a fractional bandwidth at the final IF of 10%, and a fractional bandwidth at RF of 0.1%. The normalized radian frequency range is 4.0, starting at -2.0 with a total of 32 frequency samples specified. The filter data is completed with the choice of the bandpass option.

The channel-data portion begins by indicating the number of channels to be 20. This means that the description of 20 channels will follow, although in this case not all will be used. In fact, the scenario and system description of SIGGEN:D constitutes the benchtest example illustrated in Figure 2-2. Shown there are two noise sources incident from 45° and 10° respectively. Source number 2 is given an intentional 0.1 sample-time delay. Looking at the channel parameters in Figure 2-2, it is obvious that channels 1 and 2 correspond to noise sources 1 and 2 in the scenario schematic, respectively. Channel 1 has an amplitude factor of 1.0, random number generator seed (IXO) of 1, and is incident from 45°. The first-time-on sample number is 1, and the blink duration exceeds NS (the number of signal samples, to be discussed later), so that this is a non-blinking source. The channel delay is set at 0.0. This describes noise source number 1. Channel 2 involves a distinct source with a seed that is different from that of channel 1. It is a continuous source with relative amplitude of 1.0, however, it shows a delay of 0.1 sample-time.

The output data eliminated by choice is either not needed for the next program or recalculated as needed there for purposes of convenience.

Input Data File of the Signal Generation Program, SIGGEN:D Benchtest Example (See Figure 2-2)

SPECIFICATION OF SYSTEM PARAMETERS Table 2-4.

	Ž		- 			,
LANI		MAIN ANTENNA ARRAY WEIGHTING	••	0		
IWAAP		RECEIVER AMPLITUDE AND PHASE	••	0		
IVAI		RECEIVER IMPULSE RESPONSE	••	0		
INCAP	•	CHANNEL AMPLITUDE AND PHASE	••	0		
IACI		CHANNEL IMPULSE RESPONSE	••	0		
IMSC		INDIVIDUAL CHANNEL SIGNALS	••	0		
FILTER PAR	¥ <	PARAMETERS				
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) }		;	•	- 70700	70700	
		POL (2)	••		.70700	
FBIF	•	FRACTIONAL BANDWIDTH AT FINAL IF	••			
FBRF	1	BANDWIDTH	••	.00100		
RADRNG	•	NORMALIZED HADIAN FREGUENCY RANGE	••	00000*		
PADIN	•	NORMALIZED INITIAL RADIAN FREGUENCY	••	-2.00000		
•	•		••	35		
LPBP	•	LOWPASS/BANDPASS OPTION	••	~		
		O 1 LOWPASS				
CHANNE! PAI	RA	PARAMETERS				
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0x1	•	INITIAL RANDU SETTING	••			
ī	•	FIRST-TIME-ON SAMPLE NUMBER	-	-		
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I G	•	ANGLES OF INCIDENCE	••••	45.00000		
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CHANNEL

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- BLINK DURATION IN SAMPLES - AZIMUTH ANGLES OF INCIDENCE (DEG) - CHANNEL DELAY IN SAMPLE-TIME UNITS 7: - AMPLITUDE OF NOISE SOURCE - INITIAL RANDU SETTING - FIRST+TIME-ON SAMPLE NUMBER	•	FIRST-TIME-ON SAMPLE NUMBER	•	} -
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- INITIAL RANDU SETTING : 1.000 : 1.00	•	AMPLITUDE OF NOTSE SOURCE	•	
SAMPLE NUMBER	•	INITIAL RANDU SETTING	•	00000 • 1
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CHANNEL 16 AN 1X0 N1 NB TH CDEL	<u>.</u>	AMPLITUDE OF NOISE SOURCE INITIAL RANDU SETTING FIRST-TIME-ON SAMPLE NUMBER BLINK DURATION IN SAMPLES AZIMUTH ANGLES OF INCIDENCE (DEG) CHANNEL DELAY IN SAMPLE-TIME UNITS		1.90000
CHANNEL 11 AN IXO N1 NB TH CDEL	<u> </u>	AMPLITUDE OF NOISE SOURCE INITIAL RANDU SETTING FIRST-TIME-ON SAMPLE NUMBER BLINK DURATION IN SAMPLES AZIMUTH ANGLES OF INCIDENCE (DEG) CHANNEL DELAY IN SAMPLE-TIME UNITS		1.00000
CMANNEL 12 AN 1X0 N1 NB TH CDEL	2	AMPLITUNE OF NOISE SOURCE INITIAL RANDU SETTING FIRST-TIME-ON SAMPLE NUMBER BLINK DURATION IN SAMPLES AZIMUTH ANGLES OF INCIDENCE (DEG) CHANNEL DELAY IN SAMPLE-TIME UNITS	* * * * * *	1.00000 100111 10000 -24.00000

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PORT PARAMETERS	MET	FRS		
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00		ANTENNA-ELEMENT SEPARATION FACTOR	••	1.00000
NS		NUMBER OF SIGNAL SAMPLES	••	128
NPORTS	•	A OF PORTS		21
ISP	•	PORT SELECTUR ARRAY	••	0 0 0
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PORT				
NEL	•	NUMBER OF ANTENNA FLEMENTS	••	255
L0C1	•	LOCATION OF THE FIRST ELEMENT	• ••)
BWFCTR	•	BANDWIDTH TOLERANCE FACTUR	••	1.00000
BWOFF	•	BANDWIDTH OFFSET FACTOR	••	00000
POEL	•	FRACTION OF MAXIMUM APERTURE DELAY	••	00000
PORT	~			
NEL	•	NUMBER OF ANTFINA ELEMENTS	••	-
L0C1	•	LOCATION OF THE FIRST ELEMENT	••	-
RWFCTR	•	BANDWIDTH TOLFRANCE FACTOR		1.0000
RWOFF	•	BANDWIDTH OFFSET FACTOR	••	00000
PDEL	•	FRACTION OF MAXIMUM APPRIURE DELAY	••	00000

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PORT	2			
NEL	•	NUMBER OF ANTENNA ELEMENTS	••	
L0C1	•	LOCATION OF THE FIRST ELEMENT	••	
BWFCTR	•	BANDWIDTH TOLERANCE FACTOR	••	1,0000
BHOFF	•	BANDWIDTH OFFSET FACTOR	• ••	
PDEL	•		• ••	.10000
PORT	6			
Į.	•	NIMBEO OF ANTENNA ELEMENTS	•	•
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NEL		NUMBER OF ANTENNA ELEMENTS	••	-
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POEL	•	RACTION		
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PORT	2			
NEL	•	NUMBER OF ANTENNA ELEMENTS	••	-
ر ا	•	LOCATION OF THE FIRST ELEMENT		1
BWFCTR	•	BANDWIDTH TOLERANCE FACTOR		1.00000
BHOFF	•	*	••	00000
POEL	•	FRACTION OF MAXIMUM APERTURE DELAY	••	00000°
PORT	9			
NEI	•	NUMBED OF ANTENNA ELEMENTS	•	-
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BWFCTR	•	BANDWIDTH TOLFRANCE FACTOR	• •	202
BWOFF	•		• ••	00000
PDEL	•	0	•	00000
PORT	7.1			•
NEL	•	NUMBER OF ANTENNA ELEMENTS	••	-
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BWFCTR	•	BANDWIDTH TOLERANCE FACTOR	**	1.00000
BUOFF	•	jo L	••	00000
PDEL	•	FRACTION OF MAXIMUM APERTURE DELAY	••	00000

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PORT 8: NEL LOC1 BWFCTR - RWOFF -	PORT 91 NEL LOC1 RNFCTR BNOFF	PORT 101 NEL COCI BUFCTR POEL	PORT 11: NEL LOCI RWFCTR - RWOFF -	PORT 12: NEL LOCI RWFCTR - RWDFF -	NEL 131 NEL LOCI LOCI - SWFCTR - SWFCTR - SPFE

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	FRACTION OF MAXIMUM APERTURE DELAY	••	00000
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_	LOCATION OF THE FIRST ELEMENT	••	163
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_	BANDWIDTH OFFSET FACTOR	••	00000
_	FRACTION OF MAXIMUM APERTURE DELAY		00000
_	NUMBER OF ANTENNA ELEMENTS	••	7
_	_	••	59
_	BANDWIDTH TOLERANCE FACTOR	••	1.00000
•	BANDWIDTH OFFSET FACTOR	••	00000
_	FRACTION OF MAXIMUM APFRTURE DELAY	••	00000
Z	NIMBER OF ANTENNA FIRMFATS	••	•
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227 1.00000 .00000 .00000 LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTUR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY LOC1 BWFCTR RWOFF PDEL

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Table 2-5. Description of Input Data for the Signal Generation Program, SIGGEN

SIGNAL GENERATION PROGRAM INPUT DATA DESCRIPTION

PRINT OPTIONS

IMANT - MAIN ANTENNA ARRAY WEIGHTING

IWRAP - RECEIVER AMPLITUDE AND PHASE

IMRI - RECEIVER IMPULSE RESPONSE

INCAP - CHANNEL AMPLITUDE AND PHASE

INCI - CHANNEL IMPULSE RESPONSE

IMSC - INDIVIDUAL CHANNEL SIGNALS

ALL THE PRINT OPTION PARAMFTERS WHEN SET TO I SERVE TO OUTPUT THE INDICATED DATA. WHEN SET TO 0 THE OUTPUT IS SUPPRESSFO. THIS IS RECOMMENDED WHEN THE OUTPUT DATA IS TO RE USED AS INPUT TO A SUBSEQUENT PROGRAM.

FILTER PARAMETERS

OL - NUMBER OF LOWPASS PROTOTYPE POLES LIMITED TO SIX.

POL(1) - LOCATION OF POLE NUMBER 1. A COMLEX NIMBER POL(2) - LOCATION OF POLE NUMBER 2. A COMPLEX NUMBER

POL (NPOL)

- LOCATION OF POLE NUMBER NPOL. A COMPLEX NUMBER. THE LAST ONF RE SPECIFIED.

FBIF - FRACTIONAL BANDWIDTH AT FINAL 1F.

FBRF - FRACTIONAL BANDWIDTH AT HF.

TWICE THE NORMALIZED HANDAINTH NORMALIZED HADIAN FREUVENCY PANGE. A GOOD VALUE 15 4.0. AT HF. • RAPRING

THE FIRST FREQUENCY SAMPLE NORMALIZED INITIAL RADIAN FREQUENCY. THE FIRST FREQUENCY SAMPLI STARTS HERE: AND THF OTHERS FOLLOW AT INCREMENTS OF RADRNG/NF. RADRNG = 4.0: THEN A GOOD VALUE FOR RADIN IS -2.0: RADIN

. . . NUMBER OF FREQUENCY SAMPLES IN PUWERS OF 2. RANGING UP TO 64. ž

LPRP - LOWPASS/RANDPASS UPTION 0 1 LOWPASS

I RANDPASS

THE BANNPASS OPTION IS USED IN MOST PRURABLE IMPLEMENTATION.

CHANNEL PARAMETERS

NCHNLS	•	NCHNLS - NUMBER OF CHANNELS PER PORT. THIS IS THE ACTUAL NUMBER OF CHAN- NELS WHOSE DESCRIPTION FOLLOWS. THE NUMBER OF CHANNELS DESCRIBED BELOW MUST BE EXACTLY NCHNLS. RANGE OF VALUES IS FROM I TO 20.
180	•	CHANNEL SELECTOR APPRAY. BY ASSIGNING 1 TO ANY ELEMENT OF THIS APPRAY. THE CHANNEL CURRESPONDING TO THE ELEMENT IS SELECTED FROM THE CHANNEL DESCRIPTIONS.
Ç		45 WHICH FULLOW. FROM AN ASSIMEI FENTS OF ISC MUST
1 3 C	•	CHANNEL SELECTOR ARRAY : 0 1 0 1 0 0 0 0 0
		1 10000001 :

- ANY REASONABLE VALUE MAY RE ASSIGNED. AMPLITURE OF NOISE SOUNCE. A GOOD VALUE IS 1.0. Z
- AND SHOULD BE A UNIQUE OUD INTEGER FOR FACH CHANNFL. FUR MULTIPATH SIMULATIONTHE SAME SEED SHOULD RE ASSIGNED TO ALL CHANNFLS WHICH IT IS USED TO INSURE THE REPEATABILITY OF RANDOM SIGNALS. THIS IS A SEED FOR THE RANDOM NUMBER GEN-REPRESENT MULTIPLE PATHS OF THE SAME SIGNAL. INITIAL RANDU SETTING. ERATOR. 1X0
- FIRST-TIME-ON SAMPLE NUMHER. THE SAMPLF NUMHER AT WHICH THE VOISE SET NI TO 1 TO REPRESENT A CONTINUOUS SOURCE. SET NI TO A VALUE HETWEEN I AND NS FOR A SOURCE IS FIRST "ON". FLINKING SOUNCE.

Z

- SET NE TO A VALUE BETWEEN 1 AND NS FOR A PLIN-NUMBER OF SAMPLES FOR WHICH TH HLINK-ING SOURCE IS ON. SET NB TO A VALUE RETWEEN 1 AND NS FOR A KING SOURCE. SET NB TO A VALUE GREATER THAN NS TO REPRESENT CONINIOUS SOURCE. MOTE THE INTERNEPENDENCE OF NI AND NR. BLINK DURATION IN SAMPLES.
- TH SOURCE ANGULAR DIRECTION OF INCIDENCE IN DEGREES.

CDEL

CHANNEL DFLAY IN SAMPLE-TIMF UNITS. USED TO REPRESENT MULTIPATH. SET TO ZEPO FOR DISTINCT CHANNEL. NOTE THAT IN ADDITION TO RELA-TIVE DELAYS SPECIFIED BY CDEL, A GROUP OF MULTIPATH CHANNELS ARE CHARACTENIZED BY THE SAME RANDOM NUMBER GENERATOR SEED. IXU.

PORT PARAMETERS

00	ANTENNA-ELEMENT	ANTENNA-ELEMENT SEPAKATION FACTOR. INTER-ELEMENT SPACIT	INTER-ELEMENT SPACING OF THE
	ANTENNA ARKAY.	DO = 1.0 FOR SPACING	OF HALF WAVELENGTH.

- NS NIJMBER OF SIGNAL SAMPLES RANGING UP TO 256.
- NIMBER OF PORTS RANGING UP TO 21. THIS IS THE ACTUAL NUMBER OF AUXILIARY PORTS PLUS THE MAIN PORT, WHOSE DESCRIPTION FOLLOWS. THE NUMBER OF PORTS DESCRIBED BELOW MUST RE EXACTLY NPORTS. ı NPORTS
- FROM THE PURT DESCRIPTIONS WHICH FOLLOW. THE EXAMPLE BELOW SELECTS PORT SELECTOR ARRAY. BY ASSIGNING 1 TO ANY ELEMENT OF THIS AR-RAY, THE BUXILIARY PORT CORRESPONDING TO THE ELEMENT IS SELECTED PORTS 2.4.10 AND 20 FROM AN ASSUMED NUMBER OF 20 AUXILIARY PORTS. NPORTS - 1 ELEMENTS OF ISP MUST BE DEFINED. PORT SELECTOR ARRAY ISP ISP
 - NIMBER OF ANTENNA ELEMENTS. NUMBER OF ELEMENTS IN THE MAIN ARRAY. - -- ı AE L

UP TO 1001 ELEMENTS MAY BE SPECIFIED.

LOCATION OF THE FIRST ELEMENT. LOCI IS USUALLY I FOR PORT 0. FOR THE AUXILIARY PORTS LOCI CAN HE ANY NUMBER BETWEEN I AND NEL. FUR TAP DELAY SIMULATION A PORT HAVING N-TAPS IS REPRESENTED NY N-PORTS WITH IDENTICAL VALUES ASSIGNED TO LUCI. ı 1007

BANDWIDTH OFFSET FACTOR RANGING FROM -1.0 TO 1.0. THIS PARAMETER INDICATED THE FILTER CENTER FREDUENCY SHIFT FROM THE DESIMED VALUE AS A FRACTION OF BANDWINTH.

BWOFF

1

PDEL

USEU TO REPRESENT TAP-DELAY

FRACTION OF MAXIMUM APERTURE DELAY. ON PORTS.

V-27

To wife.

. . .

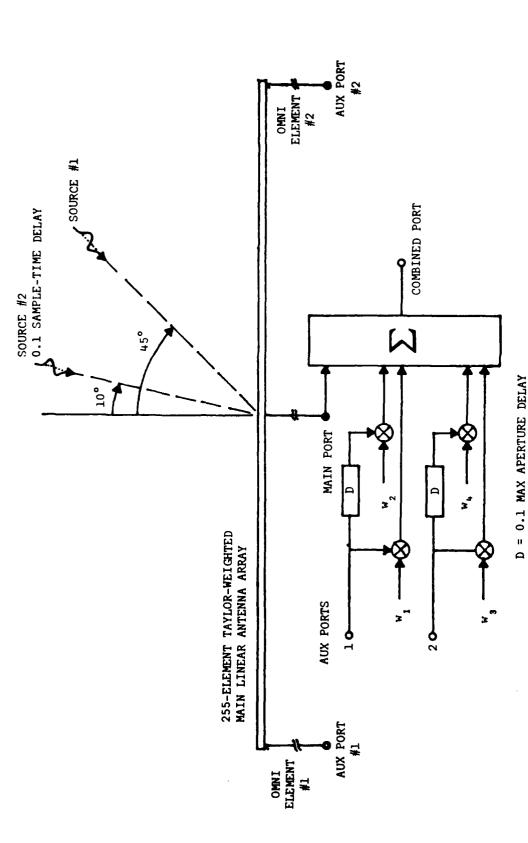


Figure 2-2. Benchtest Example. Scenario and System Description 0.1% RF Bandwidth Benchtest Example

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This delay is relative to some other signal which could be represented through the use of another channel with identical seed and zero delay, but possibly different angle and amplitude, as in a multipath situation. In this simple example, however, this was not done. For the current scenario the first two channels were selected by setting the first two elements of the selector array, ISC, to 1, and the next 18 elements to 0. This completes the channel description.

The port-data portion begins by defining the element separation to be one-half of a wavelength at RF (i.e., DO = 1.0), the number of signal samples and ports, 128 and 21, respectively. Since the main port, PORT 0, is always selected, the port-selector array, ISP, need only be defined for the 20 auxiliary ports whose description follows that of the main port.

It is evident in Figure 2-2 that in addition to the main port, two auxiliary ports are also to be used. One auxiliary is at element number 1, the other is at element 255. Each auxiliary port has two taps, the 0-delay tap and one with delay D, chosen to be 0.1 of the maximum main antenna aperture delay. This situation is clearly reflected in the port parameter description of Table 2-4. Port 0, the main port, has 255 elements. Ports 1 and 2 are shown to share element one. They are distinguished, however, by their port delays, 0.0 and 0.1, respectively. As such, the combination may be viewed as a two-tap auxiliary port at element number one. In the same manner ports 3 and 4 represent another two-tap auxiliary port at element number 255.

2.2.2 Program Structure

The signal generation program was designed to have the modular and linear structure described in the introductory paragraphs. It makes use of the modularity by following the "library" approach, i.e., referencing subprograms which are members of a larger set of programs. Data input was intentionally restricted to one branch of the program for easier maintenance, and as a natural feature of the modular concept.

2.2.2.1 Tree Diagram

The structure of the signal generation program, SIGGEN, is best demonstrated by using a tree diagram as seen in Figure 2-3. Starting with module SIGMAIN and moving along the first horizontal line, the first substructure headed by SIGSET is encountered. During execution, the first subroutine call made by SIGMAIN is to SIGSET. SIGSET in turn calls RW, RWIRC, and eventually SKIPR. So, the parallel between structure and timing is becoming evident. However, in SIGSET several other calls were made to RW, RWIRC and SKIPR, and not necessarily in that order. This is not apparent from the structure. Each time a call is made to a related subroutine, and the program branches out, control eventually returns to the next statement in the subprogram in which the first call was made. This is when a branch of the structure has been traced or completed in space or time.



Other channels could have been selected by setting their corresponding ISC elements to 1.

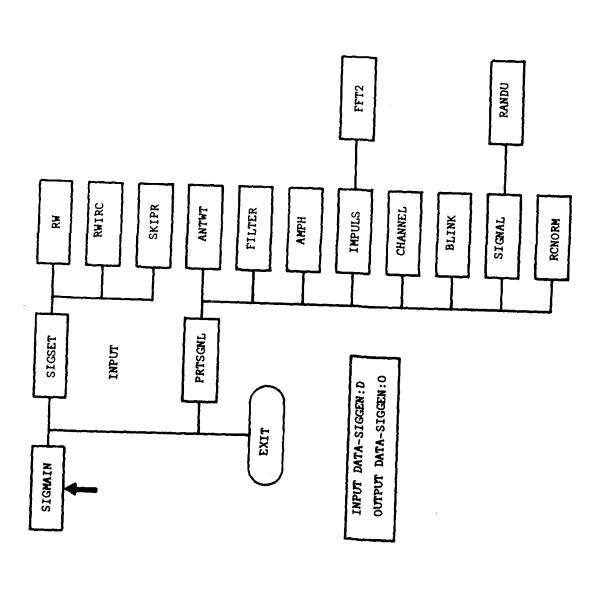


Figure 2-3. Tree Diagram of the Signal Generation Program, SIGGEN

Moving down the nearest untraced vertical line, the PRTSGNL substructure is encountered. It appears simple, and in the case of a 1-port/1-channel problem, it also represents the execution of this branch of the program. What the substructure does not show, is the iterative activity embedded into subprogram PRTSGNL. This activity is evident in the signal flow diagram of SIGGEN in Figure 2-4. There, the input data block is equivalent to the SIGSET branch discussed above. Then, at the beginning of the PRTSGNL branch the antenna array weighting is computed through ANTWT. For each execution of the port-loop the channel-loop is executed NCHNLS times, where NCHNLS is the number of channels. The port-loop is executed NPORTS times, where NPORTS is the number of ports. Once this is done, control again reverts to SIGMAIN, and EXIT is called.

Although the iterations occur on a modular level; that is, some branches are executed repeatedly, the control of the iterations is localized to the executive subprogram, PRTSGNL. Its job is simply accomplished by setting up a dual channel/port loop, making calls to the appropriate dedicated subroutines, and printing the results.

2.2.2.2 Source Modules

In the discussion of program structure, all the modules were referred to without a suffix. This was proper because of the one-to-one correspondence between source and binary modules. Thus a reference to any module applied to both types. This paragraph addresses source modules only, those with the suffix, :S.

A FORTRAN listing of all source modules comprising the signal generation source program, SIGGEN:S, is given in the next several pages under Table 2-6. A functional description of each source module of SIGGEN follows in Table 2-7.

2.2.2.3 Binary Modules

Each source module in the SIGGEN program has its binary version. Using the general JCL program introduced in Table 2-1, the binary module can be created by the method shown in paragraph 2.1.5.

2.2.2.4 Composite Binary and Load Modules

The creation of the executable load module for the SIGGEN program can be done in different ways. The JCL program, JCLSIG:BL, of Table 2-8 shows one of the methods. Here the individual binary modules are concatenated into a composite binary module, SIGGEN:B, in an order and indentation consistent with the tree-structure of Figure 2-3. This step accounts for the suffix B in the JCLSIG:BL-name. The next step of the program is to link this composite binary with the system library. This is done through the LYNX command. If all references in the linked programs are satisfied, then an executable load module, SIGGEN:L is created. This accounts for the suffix L in the JCL program name. This name, JCLSIG:BL is simply a convenient and expressive identifier, and it is not required to be in that form.

The execution of the concatenate-link JCL program is done with the interactive command

!BATCH JCLSIG:BL

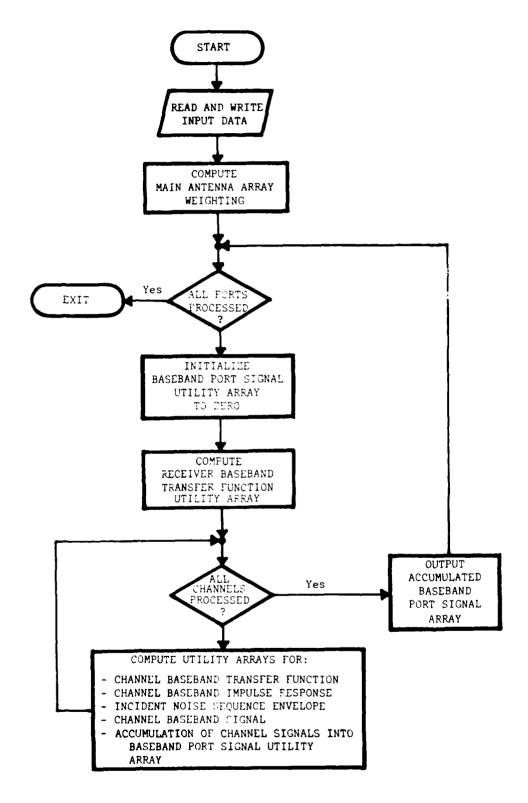


Figure 2-4. Functional Flow Diagram of the Signal Generation Program, SICCEN

FORTRAN Listing of Source Modules Comprising the Signal Generation Program, SIGGEN:S Table 2-6.

	SIGNAL GENERATION PROGRAM : SIGGEN:S COMPUTATION OF COMPLEX BASEBAND SIGNALS AT MULTIPLE RECEIVER PORTS CONNECTED TO SPECIFIED LINEAR ARRAYS CONNECTED TO SPECIFIED LINEAR ARRAYS CONNEGINAL : APRIL 19, 1980 REVISION : JANUARY 5, 1981 CHEVISION : JANUARY 5, 1981 CCALL SIGNAL SON MOTOROLA GOVERNMENT ELECTRONICS DIV. TEMPE, ARIZONA 85282 CCALL SIGSET CALL PRISGNL	END
--	---	-----

SUBROUTINE SIGSET SUBROUTINE SIGSET SPECIFICATION OF SYSTEM PARAMETERS SPECIFICATION OF SYSTEM PARAMETERS ORIGINAL : JUNE 1, 1980 REVISION : JANUARY 15, 1981 PREPARE BY : S. M. DANIEL & 1. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS DIV. TEMPE. ARIZONA 85282	INPUT : DATA FILE SIGGEN:D QUIPUT : DATA FILE SIGGEN:D QUIPUT : DATA FILE SIGGEN:D QUIPUT : DATA FILE SIGGEN:D COMPLEX POL.CDUM COMMON /SIGO/ IWANT.IWRAP.IWRI.IWCAP.IWCI.IWSC COMMON /SIGO/ IWANT.IWRAP.IWRI.IWCAP.IWCI.IWSC COMMON /SIGO/ IWANT.IWRAP.IWRI.IWCAP.IWCI.IWSC COMMON /SIGO/ AN(20).TH(20).CTAU(20).NJ(20).NJ(20).NB(20) 1SC(20).IDC(20).NCHNLS COMMON /SIGO/ WFCTR(21).BWOFF(21).PTAU(21).DO.NEL(21).LUCI(21) COMMON /SIGO/ WFCTR(21).BWOFF(21).PTAU(21).DO.NEL(21).LUCI(21) COMMON /SIGO/ AN14(14) DATA PI/3.14159265/ FORMAT(1H1) FORMAT(1H1) FORMAT(1H1) FORMAT(1H1)	READ IN SYSTEM SPECIFICATIONS FROM SIGGENTID READ IN PRINT OPTIONS CALL RWITC (CDUM, RDUM, IWANT, 0) CALL RWITC (CDUM, RDUM, IWSC, 0) CALL RWITC (CDUM, RDUM, IWSC, 0) CALL RWITC (CDUM, RDUM, IWSC, 0)
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                                                                                                                                                                                                                                                                                                                                                                                                              RWINC (CDUM+NDUM+N1 (1C)+0)
                                                                                                                                                                                                                                                                                                                                                                                                                         RWINC (COUM. NOUM, NB (IC) .0)
                                                                                                                                                                                                                                                                                                                                                                                                                                     RWIRC (COUM. TH(IC) . IDUM.1)
                                                            RWIRC (COUM.RADRNG. IDUM.1)
                                                                                                                                                                                     RWIRC (CDUM+RDUM+NCHNLS+0)
                        RWIRC (POL (I) .RDUM. IDUM. 2)
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                                                                                                                                                                                                                                                                                       IF (NC2.6E.NCHNLS) NC2=NCHNLS
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                                   RWIRC(COUM.FBIF.IDUM.1)
                                               RWIRC (COUM.FBRF. IDUM.1)
                                                                                                                        CALL PHIRC (CDUM.RDUM.LPBP.0)
RWING (COUM.RDUM.NPOL.0)
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                                                                                     RWIRC (COUM.ROUM.NF.0)
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                                                                                                                                                                                                                                                                                                                                                  CALL RW(2)
                                                                                                                                                                                                                                                                                                                                                                          100 (10) #1
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READ (105,200) ARIA, (ISP(IP), IP=NP1,NP2) WRITE(108,200) ARIA, (ISP(IP), IP=NP1,NP2)
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                                                                                                                                                                                                                                                         RWIRC (COUM. SWFCTR(1) . IOUM.1)
                  READ IN AND PACK PORT PAHAMETERS
                                                                                                                                                                                                                                                                   RWIRC (COUM. BWOFF (1) . IDUM. 1)
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                                                                                                                                                                                                                                                                                                                                                                          CALL RWINC (CDUM, HDUM, NEL (IP) .0)
                                                                              CALL RHIRC (CDUM, RDUM, NPORTS+0)
                                                                                                                                                                                                                                 RWINC (CDUM.RDUM.NEL (1) .0)
                                                                                                                                                                                                                                                                               CALL RWIRC (CUUM. POEL. IOUM.1)
                                                                                                                                                                                                                                                                                                                                                                                                                       RWIRC (CDUM.PDEL. 10UM.1)
                                                       RWIRC (CDUM, DO. 1DUM, 1)
                                                                   REIRC (COUM. ROUM. NS. 0)
                                                                                                                                                                         IF (NP1 . GT . NPM]) GUTO 5000
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130. CALL RW(1) 131. C RETURN 133. END

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		GENERATION OF RECEIVED BASEBAND PORT SIGNALS
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15.	INPUT	SYSTEM PARAMETERS IN COMMON
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19.	COMPLEX POL +	
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21.	COMMON /SIGI/	
22.	COMMON /SIG5/	AN(20),TH(20),CTAU(20),IX0(20),N1(20),NB(20)
23.	- 1 SC (20) • IDC (20) • NCHNLS	20) •NCHNLS
24.	COMMON /SIG3/	COMMON /SIG3/ BWFCTR(21).8WOFF(21).PTAU(21).DO.NEL(21).LUC1(21)
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27.	- • AM (64) • PH (64	AM(64).PM(64).X(128).AL(1001).P(64).1BLNK(1056)
28.		
29.	200 FORMAT(1X,79())	
30.		FORMAT (37X++PORT++13+/+37X+7(+-+1)
31.		FORMAT(23%, RECEIVER BASEBAND CHARACTERISTICS)
32.		FORMAT (29X; +PORT + , I 3,5X++CHANNEL +, I 3, /, 29X+22 (+-+))
33.		FORMAT(24x • CHANNEL BASEBAND CHARACTERISTICS •)
34.	700 FORMAT (24X++F	ORMAT(24X+*RECEIVED BASEBAND CHANNEL SIGNAL*)
35.	800 FORMAT (8F10.5)	
36.	L	ORMAT(25%. HECEIVED BASEBAND POHT SIGNAL.,/,19%
37.	NORMALIZATION CONSTANT	ON CONSTANT 1 1,0E13.6)
38.		
39•	_	PROVIDE MAIN ANTENNA AHRAY ELEMENT WFIGHTING
•0•		
•!• •		CALL ANTWI(NEL(1).LOCI(1).AL.IWANT)
•2•		
4 3.		DEKIVE BASEBAND PORT SIGNALS

\$ 5	DO 10 IP=1.NPORTS
•9•	Ibwl = Ib-I
47.	IF (IMPAP.EC.O.AND.IMRI.EC.O) GOTO 1000
9	#RITE(108•100)
50.	WRITE(108,300) IDP(IP)
51.	WRITE(108,200)
53.	1000 CONTINUE
.54.	C DESCRIPTION OF THE DESCRIPTION OF THE PROPERTY OF THE PROPER
, A	- K
57.	DO 20 15=1+NS
58.	20 SP(IS)=0
900	IF (IPM)
-02. 61.	C DERIVE RECEIVER CHARACTERISTICS
62.	
63.	CALL FILTER(NF.DRAD.RADIN.FBIF.LPBP.BWFCTR(IP).BWOFF(IP).NPOL.POL
65.	IF(IERAP.EG.1) CALL AMPH(HR.NF.AM.PH)
-99	
67.	
. 68	C DERIVE CHANNEL BASEBAND CHARACTERISTICS
70.	DO 30 IC#1.NCHNLS
71.	IF(IWCAP.EG.O.AND.IWCI.EG.O) GOTU 2000
.72.	WRITE(108-100)
74.	MRITE(108-500) 10P(1P) 10C(1C)
75.	
. 16.	_
78.	COUG CONTINUE CALL CHANNEL (NEI (10) - 1 OCT (10) - AL -DO-THITT) - CTALLITY - DIALLITY)
2	- NF - ABDIN - DRAO-BEFCTR (IP) - BEOFF (IP) - FBRF - HR - H)
80.	IF (IWCAP.EQ.1) CALL AMPH(H.NF, AM.PH)
81.	CALL IMP
97.	C 16961699999999999999999999999999999999
. 4	COMPOSITE PORT SIGNAL
85.	
86.	IX#IX0(IC)

```
CALL PLINK(N1(IC).NB(IC).NF.NS.1BLNK)
CALL SIGNAL(HIMPL,NF.IX,IBLNK,P.SC.NS)
IF(IWSC.EQ.0) GOTO 3000
                                                                                                                                          CONTINUE
CALL RCNORM(SP,RDUM,SPMAX,NS,2,1)
                                                  IDP (IP) , 10C (IC)
                                                                                         (SC(I) + I = 1 + NS)
                                                                                                                                                                                                                         (SP(I), [s],NS)
                                                                                                                                SP (IS) #SP (IS) +AN (IC) #SC (IS)
                                                                                                                                                                                  10P(1P)
                                                                                                                                                                                                     SPMAX
                                        WRITE(108,200)
WRITE(108,500)
WRITE(108,200)
                                                                                                                                                                                           WRITE(108,200)
WRITE(108,900)
WRITE(108,200)
                                                                                                                                                                                  WRITE (108,300)
                                                                                         WRITE (108,800)
                                                                                                                                                                                                                         #RITE(108+800)
                                                                                                                                                              WRITE (108+100)
                                                                                                    WRITE (108,200)
                                                                     WRITE(108.700)
                                                                                                                                                                        WRITE (108+200)
                              WRITE (108.100)
                                                                                                                                                                                                                                   WRITE (108.200)
                                                                                                                       DO 40 IS#1.NS
                                                                                                             CONTINUE
                                                                                                                                                                                                                                             CONTINUE
                                                                                                             3000
                                                                                                                                                                                                                                             ຊິບ
                                                                                                                                                                                                                                           111.
                                                                                                    97.
                                                                                                                                                                        . 40
                                                                                                                                                                                  05.
           88.
89.
90.
92.
                                                                               95.
                                                                                                                       99.
                                                                                                                                100.
                                                                                                                                                                                            106.
                                                                                                                                                                                                                         .601
                                                                                                                                                                                                                                   110.
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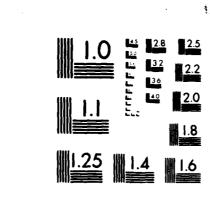
1.	ii U	REFERENCE ANTWI (NEL.LOCI.AL.)	FFFFFFF	N N N N N N N N N N N N N N N N N N N		100		RESERVES ANTER CONTINUE ANTER CONTINUE OF THE SERVES OF TH
.		# 00 # 00 # 00 # 00 # 00 # 00 # 00 # 00	PUTATI	NA NA OF		E AR	BUNNUNHHUNHHUN Butenna array Ti	BEBEEFEEFEEFEEFEEFEEFEEFEEFEEFEEFEEFEEFE
ທຸ່	u u		PROGRAM	M		_	18	
:-	· U		ORIGINAL	NAL			19.	1980
8	U		REVISION	NOI		••	SEPTEMBER 1. 19	1980
• •	ن د		PHEPARED		Β¥	••	S. M. DANIEL 6	I. KERTESZ
	, U		•				RADAR SYSTEMS AN	
12.	υu						MOTOROLA GOVERNMI Tempe, arizona (MOTOROLA GOVERNMENT ELECTRONICS DIV. Tempe, arizona 85282
*						•	MINDED OF ELFMENTS	FINE STATE OF THE
15.	ں د		 	LOC 1				
12:	, U		!	•				
18.	U	OUTPUT	•	AL.			ARRAY ELEMENT WEIGHTING	
19.			CON AL		11 16 10 44		19 19 19 19 19 19 19 19 19 19 19	BLARKHRINGHRINGHRINGHRINGHRINGHRINGHRINGHRING
21.	00	FORMAT (1H1)	THI)	,				
22.	200	FORMAT (1X, 79(1-1))	1X.79					
23.	300	FORMAT (20X . TAYLOR	120X++1	AYLOR		GHI	NG FOR MAIN ANT	WEIGHTING FOR MAIN ANTENNA ARRAY 1-20X
24.		-,39(1)						
52.	004	FORMAT (8F10-5)	18F 10 - 5					
26.		DATA PI/3.1415965/ P12=2#D1	[/3•1•]]	2965/				
28.		100=1001-1	7-10					
53.		CON2=0.5* (NEL+1)	.5* (NEL	11:				
30.		CONIEP	12/NEL					
31.		00 10 1#1+NEL	# 1 o Ne (
36.		ARGECONI* (LOC-CON2)	11 • (LOC		_			
• • • •	10	AL (1) =1+0.5*COS (AHG)	1+0-5*	30S (AH	6			
35.	•	IF (IM.EG.O) RETURN	1 (0.0	RETURN				
36.		MRITE (108,100)	108 • 100	2 2				
98.		WRITE (108,300)	108.300	: =				
39.		WRITE (108,400)	108.40		3	[=]	(AL(I)·I=1,NEL)	
* 0 * • 1 •		WELLE (1984600) RETURN	026901	3				
42.		ENO						

	SUBROUTINE FILTER (NF. DRAD. RADIN. FBIF. LPBP. BWFCTR. BWOFF. NPOL. POL
, • • • • • • • • • • • • • • • • • • •	ELECTRICAL STREETS STR
	LOWPASS PROTOTYPE FILTER OR ITS BANDPASS EQUIVALENT
	: FILTERIS
11. 12. C	ORIGINAL : APRIL 19. 1980 REVISION : JUNE 23. 1980
13.	PHEPARED BY 1 S. M. DANIEL 6 1. KERTESZ
	RADAR SYSTEMS ANALYS MOTOROLA GOVERNMENT
18.	INPUT : NF - NUMBER OF FREQUENCY SAMPLES
	DRAD
21. C	FRIF - FRACTIONAL BANDWIDTH AT FINAL IF
	- LOWPASS / BANDPASS OPTION
	1 LOWPASS
, vo	-
	•
	L - NUMBER OF
29.	POL - POLE LUCATIONS
	OUTPUT : H - SAMPLED TRANSFER FUNCTION
	BRESSERSESSESSESSESSESSESSESSESSESSESSESS
36. 37. C	ADJUST INCREMENT AND INITIAL RADIAN FREGUENCY COMPUTE SAMPLED TRANSFEH FUNCTION
	DRADL=0.5+DRAU/BWFCTR RADI=(RADIN/2-BWOFF)/BWFCTR-DRADL
41. 42. 43.	UO 10 IMI+NP RADMRADI+I+ORAUL H(I)#1

S=CMPLX(0.RAD)
IF(LPBP.EQ.1) S=S*(1+1/(1+RAD*FBIF))
DO 10 J=1+NPOL
DEN=S-POL(J)
H(I)=H(I)*POL(J)/DEN
HETURN
END 44. 45. 47. 48. 50.

```
MOTOROLA GOVERNMENT ELECTRONICS DIV.
                                                                                                                                                         NUMBER OF FREQUENCY SAMPLES, IN
                                                                                                                                                                                                                                                                    FORMAT(32X++1MPULSE RESPONSE++/+32X+16(+++)+/+(8F10.5))
                                                                                                                     RADAR SYSTEMS ANALYSIS GROUP
                                                                                                           I. KERTESZ
                                                                                                                                                                             SAMPLED TRANSFER FUNCTION
                              EVALUATION OF SAMPLED IMPULSE RESPONSE
                                                                                                                                                                                                  COMPLEX IMPULSE RESPONSE
                                         FROM A SAMPLED TRANSFER FUNCTION
                                                                                                                                            TEMPE. AHIZONA 85282
                                                                                                                                                                                                             AUXILIANY REAL ARRAY
                                                                           MAY 11. 1980
                                                                                                           S. M. DANIEL
                                                                                     JUNE 7. 1980
                                                               IMPULSIS
         SUBROUTINE IMPULS (NF+H+X+HIMPL+)
                                                                                                                                                                                                                                                                                                                                                                                                                                        (HIMPL(I) . I = 1 . NF)
                                                                                                                                                                                                                                              DIMENSION H(I) +HIMPL(I) +X(I)
                                                                                                                                                                                                                                                                                                                                                                                                       HIMPL(I) = CMPLX(X(II) + X(I2))
                                                                                                                                                                     ŧ
                                                                                                             8₹
                                                                                                                                                                                                                                                                                                                                     X(I+I) BAIMAG(H(IH))
                                                                                                                                                                                                                                                        FORMAT (11X, 79(1-1))
                                                                                                                                                                                                                                                                                                                                                                                                                 IF (IW.EQ.0) RETURN
                                                                                                                                                                                                  JUMIH
                                                                                                                                                                                                                                                                                                                                                            CALL FFT2(X+NF+1)
                                                                                                            PHEPARED
                                                                                      REVISION
                                                                           ORIGINAL
                                                                                                                                                                                                                                                                                                                          K(I) =REAL (H(IH))
                                                                 PROGRAM
                                                                                                                                                                                                                                    COMPLEX HOHIMPL
                                                                                                                                                                                                                                                                                                                00 10 I=3.NF2.2
                                                                                                                                                                                                                                                                                                                                                                                                                                        WRITE (108,200)
                                                                                                                                                                   ¥
                                                                                                                                                                                                                                                                                                                                                                                                                             WRITE (108-100)
                                                                                                                                                                                                                                                                                                                                                                                                                                                   WAITE (108, 100)
                                                                                                                                                                                                                                                                                                                                                                      30 20 I=1,NF
                                                                                                                                                                                                                                                                                          x(1) = x(2) = 0
                                                                                                                                                                                                                                                                                NF 2=2*NF
                                                                                                                                                                                                                                                                                                                                                                                            11=12-1
                                                                                                                                                                                                                                                                                                                                                  [HE]H+]
                                                                                                                                                                                                  DUTPUT
                                                                                                                                                                                                                                                                                                                                                                                 2=2*1
                                                                                                                                                                                                                                                                                                                                                                                                                                                             RETURN
                                                                                                                                                                   INPUT
                                                                                                                                                                                                                                                                                                      1H*2
                                                                                                                                                                                                                                                                   200
                                                                                                                                                                                                                                                          100
                                                                                                                                                                                                                                                                                                                                                  10
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                                                                                                                                                                                                                                                                                                     28.
                                                                                                                                                                                                                                                                                                                29.
                                                                                                                                                                                                                                                                                                                          30.
                                                                                                                                                                                                                                                                                                                                    31.
                                                                                                                                                                                                                                                                                                                                                  32.
                                                                                                                                                                                                                                                                                                                                                                                                       37.
                                                                                                                                                                                                                                                                                                                                                                      34.
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                                                                                                                                                                                                                                                                                                                                                                                                                  38.
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AD-A109 927 UNCLASSIFIED	BATCH COVARIA	TEMPE AZ GOVERNI ICE RELAXATION (I INIEL) I KERTESZ	MENT ELECTRONICS D BCR) ADAPTIVE PROC RADC-TR-81-212	FSSI46.(U) F30602-80-C-0031	1/14
4 : 7					
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MICROCOPY RESOLUTION TEST CHART NATIONAL BUREAU OF STANDARDS 1963 A

AUXILIAMY RFAL ARRAY WHOSE ODD AND EVEN-NUMBERED ELEMENTS ARE THE REAL AND THE IMAGINAMY PARTS OF THE ORIGINAL COMPLEX ELECTRICAL ENGINEERING DEPARTMENT COMPUTATION OF BASE-2 DISCRETE FOURIER TRANSFORM PROF. P. RANSOM & S. M. DANIEL TRANSFORMED AUXILIARY ARRAY CHAMPAIGN-URBANA, ILLINOIS NUMBER OF COMPLEX SAMPLES FOURIER TRANSFORM UPTION REPRESENTED BY REAL AUXILIARY ARRAY X UNIVERSITY OF ILLINOIS OF A COMPLEX-VALUED TIME SERIES 15, 1969 1 FUNEWARD OFT SEPTEMBER 1. 1980 INVERSE INPUT ARRAY FFT2:S として SUBROUTINE FFT2(X+NX+IF) IF (IMOD.EG.1) FCTRE-SNXI • • IF(IF.EQ.1) SNXI=1.0/NX X(I2M1) #FCTH*X(I2M1) X(I2) #FCTR*X(I2) PREPARED BY DATA PI/3.14159265/ ORIGINAL REVISION PROGRAM (MODEMOD (I-1.2) ž L DIMENSION X(1) DO 10 1=1.NX [2M]=[2-] CTR=SNX] OUTPUT : PI2=2*PI NXS=S+NX CONTINUE SNXIE 12=2+1 0 17. 18. 19. 20. 23. 27. 33. 34. - 86 28. 35. 37. 39. 9 125. * 5 • 38.

....

DO 20 1=1.NX2.2 IP1=1+1	7-1	XIXEX(C) XIIEX(CDI)) = X	100	X=10-18x=1	DOD KENX	Ü	4	EK/2] E	X+7	KMAX=2	KMAX	EFECTERAL SECTION OF S	**************************************	12467	ESIN(TH)	Rel	9	40 KEISKMAX.2	O 30 IMANXZ.ISTEP	HAMAX # CTURCAN	THE STATE OF THE S	とうしくうとはまりこと	101	(I) =X(I) +WXTR	IP1)=X(IP1)	TINUE	WXTREER	HE (I + NSK) - RI + R	XB+(XSB+I)+IBBIB	MINUE	X=151	60T0 30	ONTINUE	XN*1#1 05 00
* • • •		• 64	50.	51.	9.6 9.3		•	56.	57.	•	59.	į	•	• (• 5 • 6	, y		67.	.69	•69	.0.		-2/-	• • •	, K	76.	77.	•	•		:	2.	83.	•	יני י	• 00

IMOD=MOD(I-1,2)
IF (IMOD.EQ.0) GOTU 50
I = 2*1-1
I 2= I i+1
X(I1) = X(I1)
X(I2) = X(I2)
X(I2) = X(I2)
ETURN
END

92. 92. 94.

- 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0	0	SUBROUTINE SUBNECTROBULE EVALUATION OF LINE INPUT : OUTPUT : DOUBLE COMP	SUBROUTINE CHANNEL (NEL-L-BWFCTR-BWOFF-FBRF-HW-H) ALUATION OF NORMALIZED CHANDLAIN AT DISCRE LINEAR ANTENNA AR WITH SPEIFI ORIGINAL I ORAD ORAD ORAD ORAD ORAD ORAD ORAD ORAD	######################################	EVALUATION OF NORMEL (NEL-LOCI-AL-DO) TH-CTAU-PTAU-NF-RADIN-DRAD -SUBROLINE CHANNEL (REL-LOCI-AL-DO) TH-CTAU-PTAU-NF-RADIN-DRAD -SUBROLINE CHANNEL (REL-LOCI-AL-DO) TH-CTAU-PTAU-NF-RADIN-DRAD AT DISCRETE RADIAN SERGANCIES INCLUDING LINEAR ANTENNA ARRAY AND RECEIVER CHARACTERISTICS WITH SPEIFILD CHANNEL AND PORT DELAYS ORIGINAL : MAY PROGRAM : CHANNEL AND PORT DELAYS ORIGINAL : MAY ORIGINAL : MAY ORDORA : S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP NOTOROLA GOVERNMENT ELECTRONICS DIV- TEMPE, AKIZUNA 65282 RADAR SYSTEMS ANALYSIS GROUP ON TEMPE, AKIZUNA 65282 TEMPE, AKIZUNA 65282 CTAU - NUMBER OF ELEMENTS IN LINEAR ARRAY LOCI - LOCATION (NUMBER) OF FIRST ELEMENT AL - ARHAY ELEMENT WEGHTING DO - ELEMENT DELAY NOTHALIZED CHANNEL SAPPLES HADIN - INITIAL HADIAN FREQUENCY INCREMENT BANDWIDTH FRAUENCY DOAD OUTPUT: H - RECEIVER SAMPLED TRANSFER FUNCTION OUTPUT: H - RECEIVER SAMPLED TRANSFER FUNCTION DOUBLE COMPLEX CH
888 887 887 887 887		COMPLEX HWOH DIMENSION HW DATA PI/3.14 RATIO=FBRF/BI DRADL=RATIO= RADI=1+RATIO=	(1) • 1592 HFCT ORAD	• AL (1) UFF) -DRAUL

The state of the s

EVALUATION OF BASEBAND CHANNEL SAMPLED TRANSFER FUNCTION CHECH+AL (J) *DCMPLX (DCOS (ARG) ,DSIN (ARG)) CHECHODCHPLX (UCOS (ARG) + DS IN (ARG)) H(I) #CHOHR(I) PDSTHEP1+D0+SIN(TH+P1/180) ARGE-RAD* (CTAU+PTAU) RAD=RAD1 + I + DRAUL ARGO*PDSTH*RAD LOC=LOC1-1 DO 20 J#1.NEL ARGEARGO .LOC DO 10 I=1.NF LOC=LOC+1 CONTINUE RETURN CHEO ຊິບ 20 60. 61. 62.

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ပပ	RESERVER REPRESENTER REPRESENTER REPRESENTER REPRESENTER ON FOR PERIODIC BLINK CONTOL GENERATOR
υc	PROGRAM : BLINKIS
, ບ	ORIGINAL 1 JUNE 12.
U ·	REVISION
UUU	PREPARED BY :
υv	
ပပ	INPUT : NI
υL	
, , ,	NS - NUMBER OF
 .	OUTPUT : IBLNK - BLINK CONTROL ARRAY HAVING (NS+NF/2) SAMPLES
U	
	DIMENSION IBLNK(1)
	NIENIENIE I
2	TET NOT TO T
•	
	NSPHENS+NF/2
	DO 20 IENIONSPH
	1+7=7
	IF (MOD) (Jone) one of cold co
	30150 17807
	C1=13
20	_
	RETURN
	E NO

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	ر	STEPPOIT I	NF SIGNAL C	IMPI	SIDDOILTINE SIGNAL (KIEDI NK. IX.D.S.NS)
, ,	•				
• •	ى ر		OMPUTATION	OF PE	COMPUTATION OF RECEIVED BASEBAND SAMPLED SIGNALS
·	, ر	•		.	TOOL TOOL
n «	ی ر		JOIN A	CNAR	MIDEBAND NOISE INTERFERENCE SOURCE
:	v				
	U		PROGRAM	-	SIGNALOIS
•	U		ORIGINAL	••	JUNE 8 1980
10.	U	-	REVISION	••	SEPTEMBEH 1+ 1980
11	U				
2:	U (FREFARED		SANA CYCTEME ANALYSTS ABOUT
• • • • • • • • • • • • • • • • • • •	ى ر				MAIOROLA GOVERNMENT FLECTRONICS DIV.
15.	ں ر				TEMPE, ARIZONA 85282
16.	U				
18.	ں ر		JALIX X	•	COMPLEX BASEBAND SAMPLED IMPOLSE DESPONSE
9	ر		ž	•	NEWBER OF SAMPLES IN KIMPL
20.	ں ر		XI	•	INITIAL HANDU SETTING FOR NOISE SOUNCE, IBLINK
21.	U		Q	•	
25.	ں ا		S	•	NUMBER OF SIGNAL SAMPLES
;;	υţ	· Tilatio	v	(NABEL FARNT DEFERVED COMPLEX BASEBAND
25.	, U		,	1	SAMPLED SIGNAL ARRAY
26.	U			***	的复数经验机械 医多种性 医多种性 医多种性 医多种性 医多种性 医多种性 医多种性 医多种性
27.		COMPLEX	COMPLEX XIMPL+S+SI		
82		DIMENSIO	N XIMPL(1)		DIMENSION ALAPTICIDATE TO AN IDANIELE STATEMENT TO A STATEMENT TO
5,6		NXHD] #NXH+]	-		
31.		-XNB LEXX			
32.		NXP] =NX+]			
33.		DO 10 I=1.NXH	1.NXH		
34.	10				
35.		1881	•		
36.		DO 20 IENXHPI.NX	NXIIDI ONX		
37.		CALL RAN	CALL RANDU(IX.IY.Z)	_	
38.		_	P(I)=IBLNK(IB)+(Z-0.5)	9.5)	
39.	20				
•0•		SN+1 = I 00 00	1.NS		
		SI#0	3		
•2•			IONX	į	
6 3.	0		(T+"dXX)	(P-14)	

一一人人 小海市

44. S(I)=SI 45. DO 50 Jal,NXM1 46. 50 P(J)=P(J-1) 47. CALL RANDU(IX-IY-Z) -48. P(NX)=IBLNK(IB)*(Z-0.5) 49. 30 IB=IB+1 50. RETURN 51. END

			NORMA	VZI 7	2	NORMALIZATION OF HEAL UR COMPLEX ARRAY
		ā.	PROGRAM		•-	RCNORMIS
Ų		80	ORIGINAL		•	AUGUST 31. 1980
		H	REVISION		-	JANUARY 26. 1981
U L		3	PREPARED	A	-	S. M. DANIEL 6. I. KERTESZ
ں ر				;	•	RADAR SYSTEMS ANALYSIS GROUP
U						
ن						TEMPE, ARIZONA 85282
. 	INPUT	ļ	ž Š	! ! !	١,	COMPLEX ARRAY TO BE NORMALIZED
, _C	•	,	X		•	REAL ARRAY TO BE NORMALIZED
, ر			×		•	ARRAY DIMENSIONALITY
ن د			ONI		•	ARHAY-TYPE INDICATOR
Ü			1			1 REAL
Ü						•
U			IOPIN		ŧ	NORMALIZING OPTION
·						0 : BYPASS NORMALIZATION
U						1 1 PERFORM NORMALIZATION
, ن			;			
U (104100		ž ;		•	MORRALIZED CORPIEX ANXAI
، د			; ; ;			ACKARLIZED KRAL AKKAI
; پ ر			**************************************			おおけれいがの最近の1000のでは HTM 1000のです PTOT - エリースタンション マズドス マスドス マンド・・・・・・・・・・・・・・・・・・・・・・・・・・・・・・・・・・・・
,	COMPLEX	Š				
	DIMENSI	5	DIMENSION CACIDANACID	2 5 X	•	AAA SAAGAA LAMA A SAAFE LAMAGAA TOO 1902
9	_		PORMAL (* *** WARNING	2	-	CHIP THE TRUE S ACCURATION AND NORTH THE COLUMN TO THE COLUMN THE
! در	i –	W Z	MAXIMUM	REA		DETERMINE MAXIMUM REAL OR IMAGINANY COMPONENT MAGNITUDE
U	OF 61VE	Z	RRAY AN	D PE	RFO	OF GIVEN ARRAY AND PERFORM NORMALIZATION IF IUPTINE!
: :						
	TELLING FO.2)	60,0	2) 6010 1666	100	c	
	DO 10 [8] NX	-		>	>	
	ABSX=ABS(RX(I))	3 CE	X(I))			
10	IF (ABS)	.61	IF (ABSX.GT.XMAX) XMAX&ABSX	XMMX	* AB	SX
ļ	IF (XMA)	. E0	IF (XMAX.EQ.0) GOTO 9999	66 0	00	
	IF (TOPIN.EG. 0)	Z		KETURN		

Table 2-7. Functional Description of the Modules Comprising SIGGEN

SIGHAINIS		MAIN EXECUTIVE PROGRAM. IT CALLS OTHER EXECUTIVE PROGRAMS WHICH TOGETHER PERFORM THE SIGNAL GENERATION TASK.
SIGSETIS	•	EXECUTIVE SUBPROGRAM. IT IS DESIGNED TO READ FROM THE INPUT DATA FILE. SIGGEN:D. USING THE GENERAL INPUT AND OUTPUT SUBROUTINES HW AND RWIRC IN ACCORDANCE TO PRESET FORMAT. ALL DATA IS MADE AVAILABLE TO APPROPRIATE SUB-ROUTINES THROUGH COMMON BLOCKS.
RW:S	•	GENERAL SUBPROGRAM. IT IS DESIGNED TO PEAD AND WRITE AN 80-CHARACTER LITERAL DATA STRING (COMMENT). NO DATA IS RETHRNED TO THE CALLING PROGRAM.
RWTRC:S	•	GENERAL SUBPROGRAM. IT IS DESIGNED TO READ AND WRITE A 56-CHARACTER LITERAL DATA STRING FOLLOWED BY NUMERI-CAL DATA MAY BE INTEGER. REAL. OR COMPLEX SCALAR. THE NUMERICAL DATA IS RETURNED TO THE CALLING PROGRAM.
SKIPRIS	•	GENFRAL SUBPROGRAM. IT IS USED TO SKIP ONE OR MURE LINNES OF THE INPUT DATA. NO DATA IS RETURNED.
PRTSGNL 15	•	EXECUTIVE SURPROGRAM. IT USES THE INPUT DATA TO GENER-ATE THE PORT SIGNALS BY CALLING A NUMBER OF DEDICATED SUBROUTINES. THIS PROGRAM MAY RE CONSIDERED THE CENTRAL EXECUTIVE PROGRAM OF SIGGEN.
ANTWTIS	•	DEDICATED SUBPROGRAM. IT IS NESIGNED TO PROVIDF A TAY- LOM WEIGHTING SEQUENCE FOR A LINEAR ARRAY GIVEN THE NUMBER OF ELEMENTS IN THE ARRAY.
FILTERIS	•	DEDICATED SUBPROGRAM. IT IS DESIGNED TO GENERATE A DISCRETIZATION OF THE BASEBAND EQUIVALENT TYANSFER FUNCTION OF EITHER THE FINAL IF BANDPASS FILTER OR A LOWPASS ALTERNATIVE.

DEDICATED SUBPROGRAM. IT IS DESIGNFD TO COMPUTE AND PRINT THE AMPLITUDE AND PHASE OF AN INPUT TRANSFER FUNCTION.	DEDICATED SUBPROGRAM. IT IS DESIGNED TO COMPUTE A SAMPLED BASEBAND IMPULSE RESPONSE FROM A SAMPLED BASEBAND TRANSFER FUNCTION.
•	•
S I HAM	IMPULSIS

CHANNEL 15	•	DEDICATED SUBPROGRAM. IT USES THE ANTENNA AND RECEIVER
		CHARACTERISTICS TO COMPUTE A RASEBAND TRANSFER FUNCTION
		ASSOCIATED WITH A PARTICULAR ANGLE OF ARRIVAL OF A SPE-
		CIFTED NOISE SOURCE.

SENERATE A	CTION CONSIST-	1.5.
S PURPOSE IS TO	F SWITCHING FUN	JENCE OF 0+S AND
DEDICATED SUBPROGRAM. ITS PURPOSE IS TO GENERATE A	DISCRETIZED PERIODIC ON/OFF SWITCHING FUNCTION CONSIST.	ING OF AN APPROPRIATE SEQUENCE OF 0.5 AND 1.5.
BLINKIS - DE	10	Ž

DEDICATED SUBPROGRAM. IT USES THE ON/OFF SWITCHING SEQUENCE TO INITIALLY TURN ON AND SUBSEQUENTLY PERIOD-	ICALLY RLINK AN INPUT NOISE SEGNENCE PROVIDED BY A RAN- DOM NUMBER GENERATOR. IT THEN USES THIS BLINKED NOISE	SEQUENCE TO PRODUCE A DESIRED NUMBER OF RECEIVED BASE-BAND SAMPLES THROUGH ITS ASSOCIATED CHANNEL VIA DISCRE-	TE CONVOLUTION WITH ITS IMPULSE RESPONSE. ITS OUTPUT IS THE INDIVIDUAL CHANNEL BASEBAND SIGNAL.
-			
SIGNAL 1S			

GENERAL SUBPROGRAM. ITS PURPOSE IS TO PROVIDE A REPEA-TABLE SEQUENCE OF NUMBERS WHICH ARE UNIFORMLY DISTRIBU-TED RETWEEN O AND 1 AND HAVE THE CHARACTERISTICS OF RANDOM NUMBERS. RANDU:S

RCNORM:S	GENERAL	SUBPROGRA	IM. IT	IS USED	10	GENERAL SUBPROGRAM. IT IS USED TO NORMALIZE REAL AND
	COMPLEX	ARRAYS.	COMPLEX	ARRAYS	ARE	COMPLEX ARRAYS. COMPLEX ARRAYS ARE NORMALIZED WITH THE
	LARGEST	LARGEST HEAL OR IMAGINARY ELEMENT.	MAGINAR	T ELEME	۲. ۲.	

Table 2-8. JCL Program JCLSIG:BL

```
1JOB 1269, DANIEL (8512) . 7, BLDG90
1LIMIT (TIME+1) + (UO+2) + (CO+16) + (ACCOUNT)
1....JCLSIG:RL.....
IPCL
C
      SIGMAIN:B.1269
                            OVER SIGGENIB
C
        SIGSET:8.1269
C
          RW18.1269
C
          RWIRC:8.1269
C
        PRTSGNL:8.1269
0000000
          ANTWT:8.1269
          FILTER:B.1269
          AMPH:8.1269
          IMPULS:8.1269
            FFT218.1269
          CHANNEL 18.1269
          BLINK:B.1269
          SIGNAL IB. 1269
          RCNORM18.1269
ILYNX SIGGENIB
                            OVER SIGGENIL
```

Table 2-9. Execution Program, JCL:X

Upon execution of this job, SIGGEN:B and SIGGEN:L are created.

2.2.3 Program Execution

The load module described in the previous paragraph can be executed upon assigning the proper input and, as an option, output files. The input file for this case is SIGGEN:D, the one discussed in paragraph 2.2.1. The output file can be the line printer output, or a disc file similar to the input file. Since the output of this program needs to be used as input to other programs, an output disc file will be generated.

One of the methods of file assignments and program execution is shown in the JCL program, JCL:X, in Table 2-9. This is also a general program in which name substitution is used for output data file (NAME:O), load module (NAME:L), and input data file (NAME:D). Upon entering the interactive command

!BATCH JCL:X 'NAME' = SIGGEN

the job is entered into the queue. When completed, the output will be in file SIGGEN:0.

2.2.4 Output File - SIGGEN:O

The output data file, SIGGEN:O, is shown in Table 2-10. It was produced by executing SIGGEN:L with input data in SIGGEN:D. The beginning of this output file is a replica of the beginning of the input file, read and printed through subroutines RW and RWIRC. Thus the output also completely describes the current system and scenario. The list of channel and port parameters this time contains only those which were indicated by the channel and port selector arrays in the benchtest example considered. The output actually produced (rather than echoed) by SIGGEN begins with the PORT O signal, and is completed with the printout of the four auxiliary port signals.

2.3 BCR Simulation Program - BCRS

The BCR simulation program applies the Batch Covariance Relaxation technique to signals generated by the SIGGEN program. In particular, BCRS computes the covariance of a batch of the auxiliary port signals, and the cross correlation of the main and auxiliary port signals. From these it estimates an adaptive weight vector which is then applied to the original signals to produce a minimum-noise combined signal. The output of the program is the adaptive weight vector, the combined signal, and power suppression achieved.

2.3.1 Input Data File - BCRS:D

The input data for the BCR simulation program is consistent with the conventions and format established for the signal generation program. The name of this data file is BCRS:D. For the benchtest example, this file is given in Table 2-11. It has two major parts, the BCR specification and the signal generation data. The first part is a special header data file, BCRS:D0, shown in Table 2-12 with entries appropriate to the example considered.

Table 2-10. Output Data File of the Signal Generation Program, SIGCEN:0 Renchiest Evample (See Figure 2-2)

		SYSTEM PARAMETERS		
		1 1		
PRINT OPTIONS				
INANI	MAIN ANTENNA ARRAY	••	•	
INRAP	RECEIVER AMPLITUDE AND PHASE	••	0	
IMAI	RECEIVER IMPULSE RESPONSE	••	•	
INCAP	CHANNEL AMPLITUDE AND PHASE	••	0	
IACI	CHANNEL IMPULSE RESPONSE INDIVIDUAL CHANNEL SIGNALS	•• ••	00	
FILTER PARAMETERS	HETERS			
NPOL - NUMB	NUMBER OF LOWPASS PROTOTYPE POLFS	••	^	
	;	· ~	70700	70700
	Pol (2)		70700	70700
FBIF -	ONAL	••	10000	
FBRF		••	.00100	
RADRNG -	NORMALIZED RADIAN FREQUENCY RANGE	*	4.00000	
Z		1 -2.	-2.00000	
	NUMBER OF FREQUENCY SAMPLES	••	32	
- A84	LOWPASS/BANDPASS OPTION 0 1 LOWPASS 1 1 GANDPASS	-	-	
CHANNEL PARAMETERS	METERS			
NCHNLS - NUMBE	NUMBER OF CHANNELS PER PORT	•	50	
180	CHANNEL SELECTOR ARRAY	-		0
		0		
CHANNEL 1:				
	AMPLITUDE OF NOISE SOURCE		1.00000	
D (Z	INITIAL RANDU SETTING	•• 1	-	
	PITAL FIRE ON DAMPIE NUMBER		1 0000	
=	AZIMUTH ANGLES OF INCIDENCE (DEG)	. 45.	45.00000	
-				

1.00000 11 10000 10.00000	1.00000 128 21 1 1 1 0 0 0 0 0 0 0	255 1 1.00000 .00000	1 1 00000 00000 00000	1 1 00000 00000 10000	1.00000 0.00000 0.00000
***************************************	************	•• •• •• ••	**************	00 00 00 00	•• •• •• ••
AMPLITUDE OF NOISE SOURCE INITIAL RANDU SETTING FIRST-TIME-ON SAMPLE NUMBER BLINK DURATION IN SAMPLES AZIMUTH ANGLES OF INCIDENCE (DEG) CHANNEL DELAY IN SAMPLE-TIME UNITS	ENS ANTENNA-ELEMENT SEPARATION FACTOR NUMBER OF SIGNAL SAMPLES NUMBER OF PORTS PORT SELECTOR ARRAY	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLEHANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY
ā	AME I	511111	= 1 1 1 1 1	~ 1 1 1 1 1	# 1 1 1 1 1
CHANNEL AN IXO NI NB TH CDEL	PORT PARAMETERS DO - AN NS - NU NPORTS - NU ISP - PO	PORT NEL LOC1 BWFCTR RWOFF	PORT NEL LOC1 BWFCTR BWOFF	PORT NEL LOC1 BWFCTR BWOFF	PORT NEL LOC1 BWFCTR BWOFF

255 1.00000 .00000 .10000 NUMBER OF ANTENNA ELEMENTS
LOCATION OF THE FIRST ELEMENT
BANDHIDTH. TOLERANCE FACTOR
BANDHIDTH OFFSET FACTOR
FRACTION OF MAXIMUM APERTURE DELAY PORT NEL LOC1 BWFCTR BWOFF

V-65

PORT 0

.27616 .12233 -1.00000 -,37046 .00267 -.23006 -.228/84 .42498 -.20944 .33689 .03788 .12494 -,38524 -.41590 -.02180 -,36072 -.00092 -.56527 .26499 .37388 .42662 11207 .15444 .25855 -,15956 .17155 .05234 .44657 .24863 .33440 .09034 -,0995 .53158 -.96805 -, 72323 -.32173 -.03938 .49784 41518 -.17883 .03017 .42138 .45397 -,05293 .33144 .08978 17532 .00878 -.25658 -.15970 -.67978 -.08097 -,19309 .29570 02263 18866 11599 -.01191 -.08121 -. 77421 -.42421 14524 • .359902E+00 .03863 -.80400 .37157 .10339 -.05661 -.13246 .18048 .04556 -,17555 -.22121 -.23864 .48894 .16574 .15092 .50369 .16876 .34287 -,08766 -.59389 .45003 .85575 -.22002 .01299 -,37763 -.51644 -.05135 -.31393 .33672 .27772 -.08516 -. 71681 .11141 RECEIVED BASEBAND PORT SIGNAL -.80850 -.51389 .33405 -.05666 -.11408 -.25093 -.22163 .23237 .15059 -,51796 -.22332 -.15840 .79052 .04592 -.23293 .76548 -.10226 .51861 -.57297 .16877 -.49589 -.29986 -.56345 -.07994 -. 70204 .34769 .21790 11257 -.17331 .68668 -. 33261 -.23630 NORMALIZATION CONSTANT -.91809 .48863 .10982 -.18506 .13504 -.25835 .31795 .03986 .09207 -.27798 -.26716 .00095 -.51348 -.43150 .35406 .04206 .36154 .29128 -.31976 .67182 .26502 .05499 13345 .07619 .26848 -.33351 -.23581 -.40163 .08524 .15594 -. 11191 .31601 -,09812 -.28359 -.27573 -.22783 -.67014 -.48174 .07142 -.60183 .66569 .06459 -.32363 -.11299 -.27935 **.**69954 .45160 .29687 -.03880 -.24890 -.64554 -.22847 .46115 .13438 -.17867 .68224 .19326 .35300 -,08945 .09462 -.86581 .20011 -.40331 .55861 -,23752 .59253 -,15848 -.05A03 .03918 -.93809 .07067 -.11284 -,11476 -,05535 .00988 -,16596 .55190 -,08280 .07159 -.20463 .26965 .16070 -,10328 .20464 .45485 .30440 -.5385¢ .14092 17843 .20007 -.41771 -.39013 .16898 -,15834 -.25491 .29671 -.01579 -.48070 -,06350 -,14506 .30583 -,30489 -.67038 ,35976 .12943 .51795 -.00055 .10718 -.60312 .05924 -.24552 -.15339 .07344 +410+ .53392 -,09846 -.02046 -.29163 .05464 -.89117 -.37581 .46477 .70177 .34198 -.21701 -.56041 -. 71101

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PORT 1

-.48880 -.15242 -38092 ,52368 .30504 -1.00000 -.58496 -,15314 .42636 -.21834 .17435 .07588 .28787 -.09097 .31528 .20098 .44397 .13871 .16292 .37641 -.44125 \$1667 -.20884 -.06036 .13347 .06469 .62380 .03858 .18164 07921 -.29433 .37524 -.37896 .29930 .00674 -.04465 -.11260 -.80477 -.26331 .28063 -, 13248 -,08992 -, 16926 .45776 -.04419 -.07790 -.26779 -.30947 -.67211 -.51941 -,42416 -,53686 -.63687 .20237 .01462 19397 .610091E+00 -82961 -27871 -28932 -21433 -.02783 16904 -.23201 .29267 .33822 .28806 .46701 .20129 01502 -.83060 .13614 -.00945 .89872 -,23829 .44777 .00489 -.65830 .56261 -.03700 .16529 .22343 -,36033 -.22688 43610 ..39201 .37187 SIGNAL -.18820 .04583 .25227 -.26588 -.37270 -.18946 -.13321 .13595 -.74155 -.07136 -.04164 .61549 -,27158 -.61482 .60848 -.53609 .40248 -.20013 -.07624 -.22590 .10187 -.42084 -.41848 -.45309 .65897 -.22215 .14301 -.48694 -.24091 -.25135 .01027 -.24357 PORT RECEIVED BASEBAND NORMAL IZATION CONSTANT -.17755 -.93500 .32677 -27327 -27327 -21072 -20447 -.23739 .01725 .17965 .36290 -.27365 -.23553 .22782 -.34048 -.24903 .10926 .16868 .29613 -,19993 .20583 .24423 .00017 .18642 .21994 .42963 23686 38777 .09911 -.09132 .44716 -.61052 -.08271 32176 17133 -.21420 -.08099 -. 72186 -.36548 -.31924 -. 12398 -.49339 -.53938 .61187 .25267 -.07058 +121+ .48876 -,15058 -.27616 -.29755 .57666 -.06628 -,13892 -,31679 -.03243 -. 10767 -,35141 .02712 -.9A208 -.02179 .03568 -.14752 -.11392 .31100 -.22691 -,25163 .15784 .50627 -,08395 -.35199 .43022 -.54907 .38858 -,61208 .61734 .02728 .26395 .05992 19411 -.06771 .30318 -,17624 .28751 .30367 25836 .11497 .53181 -.21299 -,63976 -,02352 .19736 .00668 .69815 .05773 .09187 .21314 -.66599 -. 71764 -.09107 -.47300 .76491 .31446 .17626 -,37641 .01805 .10807 -.97474 -.08795 15087 -. 16686 -.28190 .05936 -.07275 -,48834 17691 10717

Carlotte Control

!

10335 10235 10235 10256 10257		MACN	RECEIVED	ED BASEBAND	PORT SIGNA	GNAL 610608E+00		
-21286 .1626308618 .24589 .64259 .42033 .66788 .93707 .24589 .45527 .64259 .42033 .66788 .31646 .26451 .27090 .31965 .9378 .92095 .49534 .20221 .254916 .24916 .24916 .225803 .34654 .26476 .26476 .26476 .26476 .26476 .26476 .26476 .26476 .26476 .26476 .26476 .26476 .26476 .26476 .26476 .26476 .26476 .26476 .26464 .16639 .266146 .26614								
-21286 93707 -24589 64527 -64259 -42033 -607698 -664259 -42033 -607698 -664259 -42033 -607698 -66694 -207090 -017696 -66093 -220995 -95378 -66093 -22803 -14235 -66476 -53024 -10330 -61841 -22836 -22803 -14235 -28324 -10330 -61841 -22836 -22836 -22836 -22836 -22836 -22836 -22836 -22836 -22836 -22836 -22836 -22836 -22836 -22847 -31185 -22847 -28857 -28857 -31185 -28857 -28	02491	.03355	.16263	08818	.81748	-,18453	1.00000	29458
-64259 -42033 -60788 -664259 -42033 -60788 -66694 -20708 -31965 -66693 -22916 -23378 -66093 -22916 -23378 -66093 -22916 -23378 -66093 -22916 -229378 -96395 -99534 -96395 -99534 -99534 -99534 -99534 -99534 -99534 -99534 -99534 -99534 -99534 -99534 -99534 -99534 -99537 -905597 -90599 -905597 -905597 -905597 -905597 -905597 -905597 -905597 -905	98087	21286	.93707	24589	.83185	.03664	.59328	.36582
-64259 - 42033 - 60788	.26113	.69540		.45527	Ŋ	.25877	.48329	-,35991
06461 .27090 .07696 .08694 .20708 .31965 .49534 .26093 .28916 .23378 .49534 .00354 .01921 .71096 .20221 .23033 .31654 .00354 .18992 .36335 .31652 .22803 .14235 .3234 .10330 .24971 .3234 .10330 .24971 .33224 .25287 .29299 .22581 .12527 .29299 .22541 .126907 .22541 .12520 .29434 .16981 .22541 .14262 .29434 .16981 .27696 .22541 .14819 .27440 .37577 .31185 .25597 .31185 .25597 .31185 .25597	01577	-,64259	•	60788		28708	.14425	.34693
.08694 - 20708 .31965 -66093 - 24916 - 23378 -66093 - 24916 - 23378 -00354 - 01921 - 71096 - 20221 -08752 - 22803 - 14235 - 19756 - 22803 - 14235 - 24971 -19756 - 26476 - 53024 - 19756 - 24971 -38361 - 37236 - 07101 -21369 - 22910 - 12527 - 25287 -01006 - 22910 - 12950 -01006 - 22910 - 12950 -08529 - 22541 - 14262 -08750 - 229434 - 10783 - 27440 - 37577 - 14819 - 27440 - 27577 - 14819	.16590	.06461	.27090	07696	-,19333	-,36938	39666	14192
- 18729 - 20995 - 49534 - 66093 - 24916 - 23378 - 66093 - 24916 - 23378 - 100354 - 10921 - 71096 - 20221 - 18992 - 36335 - 16622 - 22803 - 14235 - 46383 - 10330 - 14235 - 10334 - 10330 - 61841 - 32165 - 10330 - 61841 - 32165 - 10330 - 61841 - 32165 - 10330 - 61841 - 3224 - 10336 - 07101 - 22287 - 22251 - 12527 - 98174 - 22945 - 22541 - 14262 - 29434 - 10815 - 22541 - 14819 - 27440 - 37577 - 14819 - 05597 - 07597	.14848	.08694		.31965	.02145	-,16564	07124	67903
66093 24916 23378 10354 10921 71096 108752 236335 24652 22803 31654 22803 14235 22803 14235 23635 16364 2324 16367 23324 22816 22817 16819 27846 22877 14819 31185 42085 22817 18350 22877 31185 42085 22857 00259	.10375	.18729	\$6602	46234	.10654	-,12410	.16072	25671
72136235720974600035401921710961087522303331654246383349424949734638326476530244 .17323269082497123836137236071010213692291025971601006229101295060852922941142622084780096229299227440375771481930682923277311854	-,30212	-,66093	24916	23378	13129	.14652	42227	-,33021
0035401921710961692236335366542280331654228033165431654316563165631656316563165631656316563165631656316563165631656316563165631656311653116	-,17230	-,72136	23	09746	.01897	.13590	28427	.29409
0875223033316542665222803316542280331654228033165431675622803142353216522647653024453073322445307383612225442622225442622225416539222541653922254165392225416539222542225416539222542225422229222541698122254222542222922254312854222922254312854222922254312854222922254312854222922254312854222922254312854222922254312854222922277311854222922277311854222922277311854222922277311854222922277312854222922277322292227732229222772229722277222572227722257222772225772225772229722277222577222772	-,19967	-,00354	01921	71096	15962	74948	51749	01636
-,08752 -,22803 -,31654 -,6382 -,22803 -,14235 -,246383 -,14235 -,24638 -,19497 -,3 19756 -,26476 -,53024 -,4 17323 -,26476 -,33224 -,4 17323 -,29086 -,24971 -,2 138361 -,37236 -,07101 -,0 101045 -,69464 -,16539 -,8 108529 -,22541 -,16539 -,08 10815 -,22541 -,16539 -,08 12837 -,10783 -,57398 -,3 16981 -,24945 -,29299 -,23277 -,31185 -,4 169829 -,23277 -,31185 -,4	51148	.20221	18992	-,36335	.19277	07815	.22331	04254
-,48622 -,22803 -,14235 -,53024 -,46383 -,19756 -,26476 -,53024 -,453024 -,10330 -,10302 -,53024 -,46324 -,28324 -,28324 -,28324 -,28324 -,28324 -,28324 -,28324 -,28324 -,28324 -,28324 -,28324 -,28324 -,28324 -,28324 -,28324 -,28324 -,28324 -,28324 -,28434 -,28327 -,16819 -,27440 -,23277 -,14819 -,37577 -,11819 -,31185 -,4007985 -,02597 -,00146 -,283277 -,31185 -,4007985 -,283277 -,31185 -,40079 -,02597 -,00146 -,283277 -,31185 -,40079 -,02597 -,00146 -,283277 -,31185 -,40079 -,02597 -,00146 -,283277 -,31185 -,40079 -,02597 -,00146 -,283277 -,31185 -,40079 -,02597 -,00146 -,283277 -,31185 -,40079 -,02597 -,00146 -,283277 -,02597 -,00146 -,283277 -,02597 -,00146 -,283277 -,02597 -,00146 -,02597 -,00146	.06712	08752		-,31654	.23836	05146	-,13878	07756
-,6583	-,30424	-,48622	22803	-,14235	29011	96609	-,30762	.30404
. 19756 26476 53024	.06820	-,46383	.34942	16464-	32462	28447	23160	.37586
.7534410330 .618416 .3216516907332244 .1732329086 .249716 .21369 .37236071010 .21369 .29255125276 .0104522910 .125276 .0104522910 .129506 .08529 .225411426229434 .3 .1283710783 .57398 .3 .16981 .4200906146 .2 .2744037577148193 .0682923277311854	.34197	.19756	.26476	53024	43914	61555	18685	19341
.32165169073322429086 .249712383613723607101021369 .292360710100100622910 .12527908529 .21755 .500331084782294529434 .316981 .4200906146 .227440375771481930682923277148193	.02313	.75344	-,10330	.61841	28966	.60655	.08191	.46258
3836137236071010 2136948674671010 5228729255125275 0100522910129500 0852922910129500 0847800962292992 0847800962294343 16981 .42009061462 2744037577148193 0682923277148193	01371	,32165	~	33224	45422	54541	-,33628	05353
3836137236071010 -21369 .48674 .420326 0104569464 .166396 .0104522910 .129500 .08529 .21755 .5010331 .0852922541142622 0847800962294343 16981 .42009061462 2744037577148193 .0682923277148193	.18200	.17323	29086	.24971	20186	.40144	-,37266	05740
-52287 .29255 -125276 -0104569464 .166396 -0100622910 .12950 .0 .08529 .21755 .500331 .108152254114262 .2 084780096229434 .3 .1283710783 .57398 .3 16981 .4200906146 .2 .2744037577148193	42744	-,38361	-,37236	07101	00402	-,19901	20547	11646
52287 .29255125275 0104569464 .166396 .08529 .21755 .500331 .1081522541142622 9817424945292992 0847800962294343 .1283710783 .573983 16981 .42009061462 .2744037577148193 .0682923277148193	.53097	.21369	+48674	.42032	.64545	07112	.46042	01821
- 01045 - 69464 .16639 - 69529 .1755 .50033 - 10815 - 22910 .12950 .008529 .21755 .50033 - 108174 - 22945 - 29299 - 22591 .16981 .27840 - 37577 - 14819 - 31685 - 607985 - 602597 - 002597 - 16350 - 62597 - 108350 - 62597 - 20	.21547	-,52287	.29255	12527	55336	20650	44781	52980
0100622910 .12950 .0 .08529 .21755 .500331 .108152254114262 .2 9817424945292992 084780096229434 .3 .1283710783 .57398 .3 16981 .4200906146 .2 2744037577148193 .0682923277148193	-,52516	01045	69464	.16639	89979	.11444	50962	42002
.08529 .21755 .500331 .108152254114262 .2 .084780096229434 .3 .1283710783 .57398 .3 .16981 .4200906146 .2 .2744037577148193 .0682923277311854	-,38674	01006	22910	.12950	.03470	47597	.19819	54335
. 10815 22541 14262 298174 24945 29299 2	.60872	.08529	.21755	.50033	•	40291	-,13090	28446
9817424945292992 084780096229434 .3 1283710783 .57398 .3 16981 .4200906146 .2 2744037577148193 0682923277311854	61051	.10815	-,22541	-,14262	.23738	41077	.06817	79295
0847800962294343 1283710783573983 1698142009061462 2744037577148193 0682923277311854	28067	98174	24945	29299	21914	23018	-,17132	31848
1283710783573983 1698142009061462 2744037577148193 0682923277311854	.03016	08478	00962	29434	.39153	44412	-,11776	64398
274403757714819069292327731185	-,30695	.12837	10783	.57398	.35383	.65887	04413	.22125
274403757714819 068292327731185 079851835002597	27802	-,16981	•42009	06146	.23955	-,25383	04047	.01365
.069292327731185 079851835002597	.06365	27440	•	14819		.01140	08118	.08872
079851835002597	-,11255	.06829	23277	-,31185	42853	24660	62527	24683
	26828	07985	18350	02597	02687	22517	.18985	.19357

PORT 3

4.

-1,00000 -.45886 -.53220 -, 13119 .26432 -.14524 .37299 .33779 .50242 -,19502 17313 .33705 .19404 .06770 -,03802 .18775 .37342 .13720 -,33856 .32112 ,36384 -.14836 .06106 .53786 -,10842 -,02551 -.34193 .11803 .03062 .07568 .08101 19791 -.04291 .04293 -.86642 .26235 -,31204 -.48456 -, 12132 -,15635 .22804 .32136 .42132 -.16501 .10885 .29959 .21523 .13566 .08202 -.27968 19071 .23836 -,36966 .07955 .00257 .03624 .18838 .01002 .09329 .39115 .03096 .27731 16450 .22604 . 779343E+0 -.67218 .54276 17217 .23386 -. 06139 .05043 .07172 -.24028 -.20566 .31954 .35754 .26222 -,02366 .86662 -,11882 .10422 -.29875 .18723 .40479 .07480 -.87491 -, 131 6-8 .36847 .43797 -,20717 .37577 .31122 -.77081 .40101 -.25361 RECEIVED BASEBAND PORT SIGNAL -.74354 .20395 .10785 .13020 00660.-.16672 .06339 -.19522 -.16157 .41812 .17093 .39797 .25114 .28543 -.03584 -.57194 .36619 -.17788 -.01252 -.30200 .10642 -.42822 -.08240 -.20103 .24513 90660*-.21317 .70947 .29595 -.62521 -.14191 -.05091 NORMALIZATION CONSTANT -.25001 -.91628 .46365 .30762 -.26839 .25908 -.26463 -. 10117 -.29418 .18026 -.36526 .12367 .34029 .28148 -,35089 .71943 .18996 -.02978 .09123 .14670 -,08959 .13930 .19735 -.09031 .14617 .06620 -.24231 .23991 -.20281 -.45706 .38727 -.23307 .44374 -.23519 .25730 -.00140 -.20566 -,20065 -,00008 -.35798 .29874 .21012 -.22577 -.15000 .62765 .04145 .03943 .07886 .20613 -. 79776 .13003 .09327 -.29634 -.27480 .02681 .31294 .15954 13717 -,37476 .29852 .10823 .14103 .14721 -.96906 .00943 -,13830 -,13662 .22468 -,03258 17053 -,07952 .20412 -.21473 -, 33762 .09150 .12049 -.11894 .35734 -,56414 -,33852 .35595 -,59280 .62030 .13452 .03093 .28348 .07620 13322 .49108 ,16655 -.07371 -, 12531 .19361 51311 -.84147 .05329 -,09156 -, 10665 -,06153 -. 14449 .41170 -.09367 .08267 -.25749 -,25396 .21649 .15369 -.04054 .24385 -. 40433 -, 39289 .43369 ,31599 -.44087 .51118 -.05444 -.03515 .26072 .09070 -,10695 .11462 .06242 .11695 -.06191 .15041

PORT 4

-.86610 -,32138 -.03892 -,16858 .10609 -.47955 .18853 -.12514 -.16373 .31602 .41082 .04373 .05726 .14987 .28123 .08896 -.04842 .01272 -.04268 .22364 .18842 -,36196 .06664 -,26520 .00663 .17960 .09229 .23197 .30951 -.29137 .24541 .39412 .00000 .02853 -.37372 -.33448 -.49374 .20013 -.20702 -.07539 .03077 -,14539 -,10598 .52855 ,12626 -.28070 ,15364 -,37398 .35608 -,32227 -.37348 ,33096 -.06845 -.03344 -.34407 -,18200 -.07556 -.54147 .46831 -,16661 -.20771 .15461 -.06727 12121 .780274E+00 -.73378 .10913 .11663 -.08949 .05573 -.06102 -,19245 .40113 -,56345 -,30015 -.17014 .41300 .24063 .36826 -. 1731A -.00558 .10630 ,16264 .20201 .28383 -.42871 -,21103 .28910 -.09104 -,63001 -.13571 16801 -,03921 .71631 -.08094 .25304 RECEIVED BASEBAND PORT SIGNAL .86342 -.17855 .05354 .12508 -.04088 -.06110 .21472 -.30777 -.35328 .02728 --11078 .77471 -.24909 -.21584 -.16307 .23598 -.38935 .66054 -.54062 -.87153 .11499 .29847 .21937 -,32143 -,37081 -,37201 -.26064 -,18465 43991 .25127 -.39669 .06323 NORMALIZATION CONSTANT -,21909 -.80002 .43556 .13039 .25729 -.21060 -,19682 .00836 .14133 -,36810 .31059 -.23405 -.29244 -.28607 .03116 -21894 -.22750 -.17236 .61984 .07754 -, 12736 .21305 10610 14169 -.00227 .29481 .17013 .03237 .05577 .36908 .28883 .0932 .23329 -,45162 -,30803 .26768 -,25776 .26797 .09810 .25794 -,29183 .04543 -,11093 .91825 .09489 -,15048 .28895 .3775A -,23436 .35714 .22754 -. 711107 -,20023 .07825 -.14837 .45062 -. 17727 -. 12633 -,33737 -,14835 -,37613 -.17685 -.07721 -,19421 -.10555 -.10485 .42798 -.24299 .31092 .03492 .04396 -.06747 -.06230 .05893 -,13456 .12709 .08431 -,24216 .21189 .14949 -.04933 -.44777 -,03712 -.84023 .42044 -.09084 -.39874 -,38152 .25692 .11038 .15429 .23941 .50981 -.06044 .10331 -,50683 .13078 -.21955 -,17906 -,11226 -.03678 .00875 13186 .01814 -.49855 .07728 -,21063 19766 .32705 -,08686 .12903 -,35380 -.61690 -,28342 ****** .96786 .08469 13781 .55285 .32431 .59618 -, 12893 .03464 -, 18334 .08065 -.13175 -.19048

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THE PARTY OF THE P

The second part is identical to the signal generation program output, SIGGEN:0. Thus BCRS:D may be created by concatenating the files BCRS:D0 and SIGGEN:0. Note that the SIGGEN:0 data used here must be created with all print option parameters set to zero. Since all parameters involved in SIGGEN:0 were already discussed in the previous section only the new parameters of BCRS:D0 are defined in Table 2-13.

Referring again to Table 2-11, the print options parameters are self-explanatory. Since the subsequent program, BCRP, will need the main port signal, it is necessary to set IWSO to 1 if BCRP is to be run next.

The BCR parameter NWX refers to the maximum number of weights and is thus limited to 20, the maximum number of auxiliary ports. Its associated weight-selector array ISW is used to indicate which of the ports selected by ISP are to be weighted. As such, ISW is a subset of ISP; that is, when a component of ISP is 0, the corresponding component of ISW may not be 1. The opposite condition is allowed.

The BCR program is allowed to go through at most 20 iterations, the maximum number of ports. So, unless fewer iterations are intended, ITERX, the maximum number of iterations, need not be changed. No other BCR parameter need be changed.

2.3.2 Program Structure

The BCR simulation program was designed with the same methods as the signal generation program. It has a similar modular-linear structure with the data input restricted to one executive program branch. The use of the "library" approach is demonstrated more convincingly by referencing subprograms which were first introduced for the SIGGEN program. Details of the program are shown in the following paragraphs.

2.3.2.1 Tree Diagram

The structure and modular order of execution of the BCRS program are clearly demonstrated by the tree diagram of Figure 2-5. The data input is done in the BCRSET branch, again using the utility subprograms RW, RWIRC, and SKIPR. This is a method similar to the one used in SIGGEN.

After input, the central executive subprogram takes over in the BCREXEC branch. The first task here is the computation of the covariance matrix C and forcing vector <u>b</u> via subprogram CANDB. Using the computed C and B, the iterative BCR process is applied in subprogram BCRSIM to estimate the adaptive weight vector, <u>w</u>. The final task is completed in the CMBSGNL branch where the main port signal and the weighted auxiliary port signals are accumulated as the combined signal. The power suppression ratio is also calculated here.

2.3.2.2 Source Modules

The source program list of BCRS is shown in Table 2-14. To each subprogram in this list, there is a corresponding named module in the BCRS tree diagram. Since all of these subprograms are members of RADAR:LIB, those member-programs (i.e., RW, RWIRC, etc.) already employed in connection with SIGGEN are not listed. The functional description of the modules comprising BCRS, excluding those common to SIGGEN, is given in Table 2-15.



Table 2-11. Input Data File of the BCR Simulation Program, BCRS:D Benchtest Example (See Figure 2-2)

DIGITAL ADAPTIVE ARRAY PROCESSING USING BATCH COVARIANCE RELAXATION AAL OUTPUT OF SO AAL OUTPUT OF SI AAL OUTPUT OUTP	DIGITAL ADAPTIVE ARR USING BATCH COVARIANCE TONS OPTIONAL OUTPUT OF SO OPTIONAL OUTPUT OF SI OPTIONAL OUTPUT OF SI HAXIMUM NUMBER OF SIGNAL SAH SIZE OF BAND DIAGONAL MAXIMUM NUMBER OF VEIGHTS WEIGHT SELECTOR ARRAY
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INCI	•	CHANNEL IMPULSE RESPONSE	••	0
INSC	•	INDIVIDUAL CHANNEL SIGNALS	••	•
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		O : LOWPASS		
		1 : RANDPASS		
CHANNEL PARAMETERS	ARA	METERS		
	ĺ			
NCHNIS	1	NUMBER OF CHANNELS PER PORT		
ISC	1	CHANNEL SELECTOR ARRAY	1 0	
			>	>
INNAHO	•			
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1 X 0	1	INITIAL RANDU SETTING	-	-
7	•	FIRST-TIME-ON SAMPLE NUMBER	•••	
2	•	BLINK DURATION IN SAMPLES	10000	00
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CDEL	•	CHANNEL DELAY IN SAMPLE-TIME UNITS	00000	00

1.00000 11 10000 10.00000 10.00000	1.00000 128 21 1 1 1 1 0 0 0 0 0 0	255 1 1.0000 .0000	1.0000 .00000 .00000	1.00000 .00000 .10000	255 1.00000 .00000
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AMPLITUDE OF NOISE SOURCE INITIAL RANDU SETTING FIRST-TIME-ON SAMPLE NUMBER BLINK DURATION IN SAMPLES AZIMUTH ANGLES OF INCIDENCE (DEG) CHANNEL DELAY IN SAMPLE-TIME UNITS	ERS ANTENNA-ELEMENT SEPARATION FACTOR NUMBER OF SIGNAL SAMPLES NUMBER OF PORTS PORT SELECTOR ARRAY	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY
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-89117 -93809 -86581 -91806 -51340 -7164189117 -93809 -86581 -91809 -51389 -7164180117 -93809 -86581 -91809 -51389 -7164106456 -11264 -27573 -25635 -11408 -03865 -10456 -10467 -10456 -10467 -22732 -22737 -18048 -24677 -24677 -26716 -27798 -12646 -12546 -10556 -10667 -10667 -10		AGCN	RECEIVED PMALIZATION (ED BASEBAND N CONSTANT	PORT SIGNAL	NAL 359902E+00	• • • • •	! ! ! ! !
	.05464	381	27935	1850	.8085		96805	-1.00000
	89117	9380	86581		.5138	-		•
23752283591350405666103391128427573258351140803863056610553529687 .0398622163132460556605988056810553529687 .03986221371804813246227798150590455615098223371804826716217981505917555221212549126716217981509222332221212549126483601834315023351158402386416370228870459417331087661627459389220463665692238115848173310876610328173455938922046317845253300549929986012992538541733108765259861733108763250861114115848098121119170204313931119170204313931129115834112911583411291158341129112572177217843112991259421129912594112572777217843112991259421129912594112572777217843112992159411257277721784311299215942112992112991125727772178431129921129421129921129421129921129421129121129921129	.51795	.07067	. 69954	.48863	.33405	.37157	-, 72323	56527
-11284275732583511408 .038630566105535 .29687 .0398622163132460556822783227831324613246227832278315059 .045562278322779 .15059175552280227792277922861228042280522332228642280422805223322286422805228	48070	23752	28359	.13504	05666	,10339	.17505	.00267
	06350	-,11284	27573	25835		.03863	.07952	.27616
05535 .29687 .039862216313246 .0098602278327798 .15059 .04556 .200072278327798 .15059 .04556 .2000724890 .000952233222121 .0828048174333511584023864 .0828048174333511584023864 .20461455451348 .20463601834315023268 .20464 .13438 .291281733108766 .304022887 .042061733108766 .304022887 .0540925996 .30440 .19326255815729759389 .30440 .19326255815729759389 .30440 .19326255815729759389 .30440 .193262550249589 .55861 .31601 .3476905135 .5684840331401633326131393 .1584840331401632363005135 .1784320011 .26848 .17843 .17843 .17843 .17843 .17843 .17844 .20464 .20566 .20567 .20667 .20667 .20668 .2066	00055	-,11476	.45160	.31795	25093	05661	53158	23006
165960388009207232371804816596227832779815059045561755520007670142671651796175552000764890000952233222121182800828048174333511584023864254916455451348045921657420463601834315072329315092264632046360183431507293915092264641032846115261281733108766417710645923581572975938920464390131786731976168774500329986538543530005499259986538545385455861568484918140163332613139305804158341583416898401633326131393058161583415	.10718	05535	.29687	.03986	221		-,32173	22894
165962278327798 .15059 .0455617555	-,37581	.00988	03880	.09207			-,03938	.26499
. 20007	60312	-,16596	2278	•		.04556	49784	.37388
- 55190 - 24890 . 00095 - 22332 - 22121 - 15840 - 23864	.05924	.20007	67014	•		-,17555	.41518	.42498
0828048174333511584023864 .07159 .07142 .10982 .79052 .46894 254916455451348 .04592 .16574 .26965 .66569 .35406 .753293 .15092 .26965 .66569 .35406 .76548 .50369 .1607022887 .0420610226 .16876 .20464 .13438 .291281733108766 .390131786731976 .168775938922002 .390131786731976 .168775938922002 .53854 .35300 .0549929986 .01299 .53854 .09812 .0761907994 .111141 .5925308945 .133455634531763 .59671 .55861 .316017020451644 .15834 .20011 .26848 .21790 .33672 .1689840331401632353008516	.46477	.55190	24890	.00095	-22	•	17883	20944
254916455451348 .04592 .16574 .254916455451348 .04592 .16574 .1656636618343150723293 .15092 .15096 .16670 .26965 .66569 .35406 .76548 .50369 .1607022887 .0420610226 .16876 .260464 .13438 .2912810226 .16876 .34287 .20464 .13438 .291281733108766 .16876 .45938922402 .259389 .22602 .15848 .95300 .05499299996 .01299 .2538508945 .1334556345516441584809812 .0761907994 .11141158484033140163332613139311191702045164415834 .20011 .26848 .21790 .33672 .11267 .2178311299 .11257 .27772 .17843 .20011 .26848 .2179009516 .11257 .27772	-,14506	08280	48174		.15	-,23864	.03017	.12233
254916455451348 .04592 .16574204636018343150723293 .1509250465 .66569 .35406 .76548 .50369 .1607022887 .0420610226 .16876 .16876 .22065 .3428751861 .3428751861 .3428759013173108766 .1593895729759389590131731186751861 .35309229986 .012992538508945 .1334526345220021584809812 .0761907994 .111411584809812 .0761907994 .11141158484033140163332613139315834 .20011 .26848 .2179033367215834 .20011 .26848 .217900513515834 .20011 .26848 .2179005135 .11257 .27772	24552	.07159	.07142	.10982	. 19052	48894	.42138	. 42662
20463601834315023293 .1509226965 .66569 .35406 .76548 .50369 .1607022887 .0420610226 .16876 .36154 .51861 .34287 .291281733108766 .35064 .13438 .291281733108766 .1593892360131734117867235815729759389572975938953285 .30440 .19326 .265024958922002538854 .35300 .0549929986 .012991584809812 .0761907994 .111411584809812 .0761907994 .11141158484033140163332613139315834 .20011 .26848 .2179033367215834 .20011 .26848 .21790333672 .117843 .20011 .26848 .2179005135 .117843 .20011 .26848 .2179008516	56041	25491	64554	S.	.04592	.16574	.45397	.33689
.26965 .66569 .35406 .76548 .50369 .1607022887 .0420610226 .16876163284611536154518613428720464 .134382912817331087661733108766173310845923581572975938923603454856822467182686688557559389220022385435300 .054992998601299220022585435300 .0549929986012992585308945 .133455634537763584809812076190799411141558613160134769051359567155861316013476905135958721583420011268482179033372112572777217843094621559411257277721784309462155941125727772	-,15339	20463	601A3	43150	- 4.23293	.15092	05293	.03788
-10328	.70177	.26965	• 66569	.35406	v	.50369	.33144	.11207
10328 .46115 .36154 .51861 .3428720464 .13438 .29128173310876623601317867235815729759389239013178675938925901317867593892200223854 .35300 .0549929986 .012992505308945 .1334556345377631584809812 .0761907994 .1114115848403314016333261313934033140163332613139315834 .20011 .26848 .2179033367215834 .20011 .26848 .21790085162353008516	.34198	.16070	22887	.04206	~	.16876	.08978	.24863
.20464 .13438 .29128173310876641771 .064592358157297593892390131786731976 .16877 .4500323901317865 .6824 .68268 .855752538526986 .0129922985 .08945 .1334526986 .012991584808945 .1334556345377631584808912 .0761907994 .1114126671 .55861 .31601 .347696513515834 .20011 .26848 .21790 .33672 .3158311299 .08524 .11257 .27772 .17843 .09462 .155942353008516	.07344	~	.46115	*36154	.51861	.34287	.17532	.33440
41771 .064592358157297593892390131786731976 .16877 .4500355485 .68224 .67182 .68668 .85575553854 .35300 .0549929986 .0129925925308945 .1334556345377631584808945 .11191702045164415848403314016333261313934033140163332613139315834 .20011 .26848 .21790 .3367215834 .20011 .26848 .21790 .3367215834 .20012558542159008516	01579	N	13438	.29128	17331	08766	.00878	.12494
390131786731976168774500345485682246718268668855752040193262650249589220022998601299299253089451334556345377631584809812 .0761907994 .1114176503323633114176898403314016333261313934033140163332613139315834200112684821790336721583420011268482179033672178439462155942363008516	21701	41771	•06459	23581	•	59389	25658	-,38524
45485 .6824 .67182 .68668 .85575 30440 .19326 .26502 49589 22002 2 .53854 .35300 .05499 29986 .01299 2 .59253 08945 .13345 29986 .01299 3 15848 09812 .07619 07994 .11141 4 05803 32363 11191 70204 51644 5 29671 .55861 .31601 .34769 05135 6 .16898 40331 40163 33261 31393 3 15834 .20011 .26848 .21790 .33672 3 1694 11299 .08524 .11257 .27772 3 17843 .09462 .15594 23530 08516	71101	-,39013	17867	31976	.16877	.45003	-,15970	.15444
3 .30440 .19326 .26502495892200253854 .35300 .0549929986 .0129929986 .0129929986 .0129929986 .0129929986 .0129929986 .0129929986 .0129929986 .01299295831584809812 .0761907994 .1114126871 .55861 .31601 .347690513529671 .25861 .31601 .347690513515834 .20011 .26848 .21790 .33672 .3139315834 .20011 .26848 .21790 .33672 .317843 .09462 .155942363008516	******	•45485	.68224	+67182	.68668	.85575	08121	,25855
9 53854 .35300 .05499 29986 .01299 2 .59253 08945 .13345 56345 37763 8 15848 09612 .07619 07994 .11141 6 26671 .55861 .31191 70204 51644 6 .16898 40331 40163 33261 31393 3 15834 .20011 .26848 .21790 .33672 3 .14092 11299 .08524 .11257 .27772 3 .17843 .09462 .15594 23630 08516	.30583	30440	•19356	.26502	49589	•	67978	41590
2 .5925308945 .1334556345 81584809812 .0761907994 505803323631119170204 5 .29671 .55861 .31601 .34769 6 .16898403314016333261 315834 .20011 .26848 .21790 3 .1409211299 .0852423630	30489	w	.35300	.05499	29986	.01299	08097	02180
61584809812 .0761907994 505803323631119170204 6 .29671 .55861 .31601 .34769 7 .16898403314016333261 8 .15834 .20011 .26848 .21790 9 .1409211299 .0852423630	.53392	w.	08945	13345	56345	37763	77421	36072
605803323631119170204 5 .29671 .55861 .31601 .34769 6 .16898403314016333261 7 .15834 .20011 .26848 .21790 7 .1409211299 .0852411257	67038	-	09812	.07619	07994	111141	-,19309	00092
6 .29671 .55861 .31601 .34769 5 .16898403314016333261 315834 .20011 .26848 .21790 3 .1409211299 .08524 .11257 3 .17843 .09462 .1559423630	09846	05803	-, 32363	11191	70204	51644	42421	-,15956
6 .16898403314016333261 315834 .20011 .26848 .21790 3 .1409211299 .08524 .11257 3 .17843 .09462 .1559423630	.35976	.29671		.31601	.34769	05135	.29570	.17155
315834 .20011 .26848 .21790 .3 .1409211299 .08524 .11257 .3 .17843 .09462 .1559423630	02046	. 16898	40331	40163	33261	-,31393	.02263	.05234
3 .1409211299 .08524 .11257 . 3 .17843 .09462 .1559423630	-,29163	~		.26848	.21790	.33672	14554	\$6060
3 .17843 .09462 .155942363008	.12943	.14092		•08524	.11257	.27772	.18866	.44657
	.08273	.17843	.09462	5	23630	-,08516	.11599	09951

			PORT		1 1 1 1 1 1 1 1 1	6 6 7 7 8	; 1 1 1 1
	NOR	RECEIVED	D BASEBAND CONSTANT	PORT SIGNAL	NAL 610091E+00		
. n	<u> </u>	09132	-,17755	18820	83060	29433	-1.0000
-,21299	.982	24	93500	.04583	8296		5849
Φ	2516	.44716	.32677	.25227	2787	-,37896	488B
397	60	61052	.42171	265	.28932	•	1524
.05773	16	08271	27327	3727	2143	32	(7)
.09187	•	.32176	.21072	3	0278	67211	.0758
.21314	.11	.48308	20447	13321	11077	26331	-,1531
-,66599	.31100	21420	.24147	.14301	.13614	34743	.4263
71764	15784	08099	-,23739	.13595	00945	.29930	.2878
02352	.19411	72186	•01725	74155	.16904	*1900*	.5236
,18736	.50627	-,36548	796	07136	-,19976	04465	2183
09107	06771	31924	-,23553	04164	23201	-,08992	.14816
48834	.30318	-,12398	.22782	.61549	.29267	.28063	3050
47300	08395	49339	34048	27158	.33822	.38861	.2167
.17691	-,35199	53938	24903	61482	.44777	-,16926	.1743
.76491	02179	.61187	10926	.60848	•28806	.45776	6060
.31446	.02369	35141	.16868	53609	.46701	04419	,3152
17626	-,17624	5	961	950	.20129	07790	.3764
37641	E	07058	.36290	20013	.00489	11260	
.22704	54907	.41214	47726	~	65830	02222	4412
53181	22691	10767	27365	22590	.56261	51941	.4439
+01805	LJ.	.17133	015	18	.89872	42416	.4991
.00668	Œ	.11727	199	Ö	03700	53686	2088
.10807	61208	.48876	666	42084	.16529	26779	.1387
.10717	.61734	-,15058	058	41848	23829	80477	9
97474	.28751	27616	.24423	24091	.22343	-,30947	.1629
08795	02728	29755	.00077	45309	39201	63687	1334
.15087	.30367	•57666	.09911	589	36033	23	• 0646
-,16686	.26395	995	42963	2	22688	_	.0385
819	20	m	877	102	.37187	939	.0792
59	.11497	67	.23686	24357		41	.6238
07275	.25836	-,03243	.18642	22215	.01502	.20369	1816

			PORT	2			
		RECEIVED	ED BASEBAND	PORT SIGNA	GNAL .610608E+00		
02491	.03355	.16263	08818	.81748	18453	1.00000	29458
.98087	2128	0	24589	8318	0	•	.36582
.26113	.69540		.45527	N	.25877	.48329	35991
01577	64259	42033	60788	29770	28708	=	.34693
.16590	.06461	.27090	07696	-,19333	36938	7	14192
.14848	•08694	20708	.31965	.02145	16564	07124	67903
.10375	.18729	.20995	.49534	.10654	12410	.16072	25671
30212	66093	24916	23378	13129	.14652	42227	-,33021
17230	-,72136	.23572	09746	.01897	.13590	28427	.29409
19967	00354	01921	71096	15962	74948	51749	01636
51148	.20221	-,18992	-,36335	.19277	07815	. 22331	04254
.06712	08752	.23033	31654	.23836	05146	13878	07756
30424	48622	22803	14235	29011	.60396	30762	*3040*
.06820	46383	.34942	16464	32462	28447	-,23160	.37586
.34197	.19756	.26476	53024	+166+*-	61555	18685	19341
-02313	75344	10330	.61841	28966	• 60655	.08191	.46258
01371	.32165	16907	33224	45422	54541	33628	05353
.18200	.17323	29086	.24971	20186	.40144	-,37266	05740
42744	-,38361	-,37236	07101	00402	19901	20547	11646
.53097	.21369	.48674	.42032	.64545	07112	.46042	01821
.21547	52287	.29255	12527	55336	20650	44781	52980
-,52516	-01045	69464	.16639	89979	.11444	50962	42002
38674	01006	22910	.12950	.03470	47597	.19819	-,54335
.60872	.08529	.21755	.50033	16688	40291	13090	28446
61051	.10815	-,22541	14262	.23738	41077	.06817	-, 79295
28067	98174	24945	29299	21914	23018	17132	31848
•03016	08478	-,00962	29434	.39153	44412	11776	64398
30695	.12837	10783	.57398	.35383	.65887	04413	.22125
-,27802	16981	•42009	06146	.23955	25383	04047	.01365
.06365	27440	37577	14819	38166	.01140	08118	.08872
11255	.06829	23277	-,31185	42853	-,24660	62527	24683
26828	07985	18350	02597	02687	-,22517	.18985	.19357
	100000000000000000000000000000000000000				1		

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PORT 3

-.03802 .26432 -1,00000 -.45886 -.53220 -. 13119 ,37299 .33779 .33705 53786 -.02551 -.14524 .50242 -,19502 .17313 19404 .06770 .37342 .13720 -,33856 .32112 -,34193 .36384 .11803 -.14836 .06106 .04101 -,10842 19791 .03062 07568 .05161 -.48456 -, 12132 -.31204 -.04291 .17714 -,15835 .22804 .32116 .42112 .29959 .21523 .10885 .04293 .08202 -.27968 .23836 .36966 .07955 -.26235 .18838 -.16501 .00257 -.03624 .01002 .09329 .39115 -.03096 27731 .19071 .779343E+00 .10422 -.25361 -.20717 .31122 .26222 -.06139 .16929 .22604 .23388 -.13168 .05043 -.24028 -. 77081 .17217 .07172 -.20566 .37577 -,67218 .54276 .86662 .11662 .18723 .40479 -.07480 ,31954 ,35754 .36847 -.43797 .40101 -.87491 RECEIVED BASEBAND PORT SIGNAL .41812 .20395 .10785 .13020 00660*-.06339 -.74354 -,62521 .16672 -19522 -.16157 .17093 .28543 ..03584 .36619 -.17788 -.30200 -.42822 -.08240 90660 ---.05091 .39797 .25114 -.57194 .70947 -.01252 .10642 .29595 -.14191 -.20103 .24513 NORMALIZATION CONSTANT .46365 .23991 .12367 -.91628 .30762 -.26839 .25908 -.25001 .14617 -.26463 -. 10117 .06620 -.29418 .18026 -,36526 .34029 .28148 -.35089 .71943 .18996 .09123 .14670 -.08959 -.24231 -.20281 -.02978 .13930 -.45706 .38727 19735 17837 -.09031 .31294 .21012 -.22577 -,23307 .44374 -.23519 -.27480 -. 79776 .13003 -.35798 .25730 -.00140 .09327 -.20566 -.20065 -.00008 -.29634 -.15000 .62765 15954 .04145 03943 .07886 .13717 .20613 .14103 .14721 .026R1 -,37476 .29852 10823 .00943 -.07952 .20812 -.21473 13322 -,96906 .22468 -.03258 .12049 -.07371 -,12531 -,13662 .17053 .49108 -,33762 - 09150 -.11894 .35734 -.56414 -,33852 .35595 -.59280 .62030 .13452 -.03093 .28348 .16655 .51311 -.07620 -.84147 .05329 -.09156 -,10665 -.06153 -. 14449 .08267 -,25749 .21649 .15369 -.40433 -,39289 .43369 .51118 .06242 11695 .41170 -.09367 -,25396 -.04054 .24385 .31599 -.44087 -.05444 -.03515 .26072 .09070 -,10695 .11462 -.06191

•	
PORT	

		RECEIVED NORMALIZATION	ED BASEBAND V CONSTANT	PORT SIGNAL	GNAL 780274E+00		
03678	.03492	.23329	21909	.85342	73378	1.00000	86610
.96786	84023	.91825	80002	.77471	63001	.46831	
.08469	.04396	-,45162	.43556	24909	.22376	.52855	47955
.00875	-,10555	-,30803	.13039	17855	.10913	, 12626	03892
13781	_	.26768	23405	21584	.11663	28070	.18853
.13078	06747	-,25776	.25729	.05354	08949	.02853	-,12514
13186	06230	.09489	00227	.12508	13571	.15364	16373
-,21955	.05893	15048	.09321	16307	.16264	-,37372	.23197
.01814	-,13456	.26797	21060	04088	.05573	-,33448	.31802
-,17906	\rightarrow	.09810	19682	06110	06102	49374	.41082
-,49855	.42044	07721	.00836	.23598	-,19245	.20013	16858
.07728	09084	.28895	29244	.21472	17014	-,16661	.10609
21063	.08431		.14133	37081	.41300	34407	.30951
19766	N		36810	30777	.20201	20702	.22364
.32705	N	.25794	28607	35328	.16801	07539	.04373
08686	.21189	23436	.29481	37201	.40113	.03077	.05726
-,11226	.14949	-, 12633	.03116	38935	.24063	20771	.14987
.12903	04933	-,33737	.31059	26064	.28383	-,37398	.28123
-,35380	.23941	29183	.21894	.02728	03921	-,14539	.08896
.55285	39R74	,35714	22750	.66054	56345	.35608	29137
.32431	m	.22754	17236	54062	.36826	-, 32227	.18842
50683	. 42798	71107	.61984	87153	.71631	-,37348	.24541
-,35185	.31092	20023	.17013	.11499	17318	33096	36196
.59618	•	.04543	.03237	11078	0055A	10588	.06664
61690	.50981	11093	.05577	.29847	30015	.15461	26520
-, 12893	06044	14835	.07754	18465	.10630	06845	.00663
.03464	03712	.07825	-,12736	.43991	42871	06727	04842
28342	.25692	14837	.21305	.25127	08094	18200	.17960
-,18334	~	.45062	36908	.21937	21103	03344	.01272
.08065	_	-,37613	.28883	32143	.25304	07556	.09229
-,13175	.11534	-,19421	.10610	-, 39669	.28910	54147	.39412
19048	.15429	17685	.14169	.06323	09104	.12127	0426A
				1			1

Table 2-12. BCR Specification Auxiliary Data File, BCRS:0

USING			2 :	GITAL	ADAP	TIV	FAR	DIGITAL ADAPTIVE ARRAY PROCESSING	SSING						
RINT OPTIONS RINT OPTIONS IWSO - OPTIONAL OUTPUT OF SO IWSI - OPTIONAL OUTPUT OF SI IWCB - OPTIONAL OUTPUT OUTPU						5 i	SING								
RINT OPTIONS IWSO - OPTIONAL OUTPUT OF SO IWSI - OPTIONAL OUTPUT OF S 1 0 0 IWCB - OPTIONAL OUTPUT OF C AND B 1 1 1 CR PARAMETERS CR PARAMETERS NSX - MAXIMUM NUMBER OF SIGNAL SAMPLES 1 20 0 0 IWO - SIZE OF BAND DIAGONAL 1 1 1 0 0 0 INW - MAXIMUM NUMBER OF WEIGHTS 1 1 1 0 0 0 ITER - ACTUAL NUMBER OF ITERATIONS 1 X ITER -				BATCH	20	ARI	INCE	RELAXATI	NO						
IWSO - OPTIONAL OUTPUT OF SO IWSI - OPTIONAL OUTPUT OF SI IWCB - OPTIONAL OUTPUT OF C AND B ; 1 IWCS - OPTIONAL OUTPUT OF C AND B ; 1 IWCS - OPTIONAL OUTPUT OF SIGNAL SAMPLES ; 20 IWCS - MAXIMUM NUMBER OF SIGNAL SAMPLES ; 20 IWW - MAXIMUM NUMBER OF WEIGHTS ISW - WEIGHT SELECTOR ARRAY ITER - ACTUAL NUMBER OF ITERATIONS ; X									:						
IWS0 - OPTIONAL OUTPUT OF SO :	PRINT OP	TION	S						T	; ; ; !	į	İ		į	
IWSI - OPTIONAL OUTPUT OF SI IWCB - OPTIONAL OUTPUT OF C AND B : 1 CR PARAMETERS IND - SIZE OF BAND DIAGONAL IND - SIZE OF B	INSO	•		OUTPUT	9	00			•		-				
INCB - OPTIONAL OUTPUT OF C AND B ; I CR PARAMETERS CR PARAMETERS CR PARAMETERS CR PARAMETERS CR PARAMETERS CR PARAMETERS INC - SIZE OF BAND DIAGONAL NWX - MAXIMUM NUMBER OF WEIGHTS ISW - WEIGHT SELECTOR ARRAY ITERX - MAXIMUM NUMBER OF ITERATIONS ITERX - ACTUAL NUMBER OF ITERATIONS ITER - ACTUAL NUMBER OF ITERA - ACTUAL NU	ISAI	•	OPTIONAL	OUTPUT	9	S			• ••		- C				
CR PARAMETERS NSX - MAXIMUM NUMBER OF SIGNAL SAMPLES	IACB	•	OPTIONAL	OUTPUT	96	ပ	AND		• ••		~				
NSX - MAXIMUM NUMBER OF SIGNAL SAMPLES : 256 IWO - SIZE OF BAND DIAGONAL NWX - MAXIMUM NUMBER OF WEIGHTS : 1 1 1 1 0 0 0 0 ITERX - MAXIMUM NUMBER OF ITERATIONS : 20 ITERX - ACTUAL NUMBER OF ITERATIONS : X	BCR PARA	METE	RS												
NSX MAXIMUM NUMBER OF SIGNAL SAMPLES : 256 INO - SIZE OF BAND DIAGONAL : 20 NWX - MAXIMUM NUMBER OF WEIGHTS : 20 ITERX - MAXIMUM NUMBER OF ITERATIONS : 20 ITERX - ACTUAL NUMBER OF ITERATIONS : X		į		1	1										
IWO - SIZE OF BAND DIAGONAL NWX - MAXIMUM NUMBER OF WEIGHTS ISW - WEIGHT SELECTOR ARRAY ITERX - MAXIMUM NUMBER OF ITERATIONS ITER - ACTUAL NUMBER OF ITERATIONS	XSX	•	MAXIMUM	UMBER (S JC	IGN) 	MPLES	••		256				
NWX - MAXIMUM NUMBER OF WEIGHTS : 1 1 1 0 0 0 0 1 1 1 1 1 0 0 0 0 0 1	OAL	•		AND DI	NOOT	ہے			••		0				
ISW - WEIGHT SELECTOR ARRAY 1 1 1 1 0 0 0 0 1 1 0 0 0 0 0 0 1 1 1 1	X	•		UMBER (N → N	F16F	ITS		•		2				
ITERX - MAXIMUM NUMBER OF ITERATIONS : 20 20 10 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1	1SH	•	WEIGHT SE	LECTOR	ARR	7			•	1		0	0	0	0
ITER - ACTUAL NUMBER OF ITERATIONS	Ĭ		MAXIMUM N	UMBER ()F I	TERA	TION	Si		0	000	•	0	•	•
)	ACTUAL NU	WBER OF	11	RAT	NOI				×		İ		Ĭ

Table 2-13. Input Data Description of the BCR Simulation Program, BCRS

DIGITAL ADAPTIVE ARRAY PROCESSING USING BATCH COVARIANCE RELAXATION INPUT PARAMETER DEFINITION

PRINT OPTIONS

INSO - OPTIONAL OUTPUT OF SO

IWS1 - OPTIONAL OUTPUT OF SI

INCB

OPTIONAL OUTPUT OF C AND B
SET ANY OF THESE PARAMETERS TO 0 FOR NO-PRINT, OR 1 FOR PRINT.
THE PRINTING OF SO IS NECESSARY IF THE DATA IS TO BE USED FOR INPUT TO THE BCRP PROGRAM.

BCR PARAMETERS

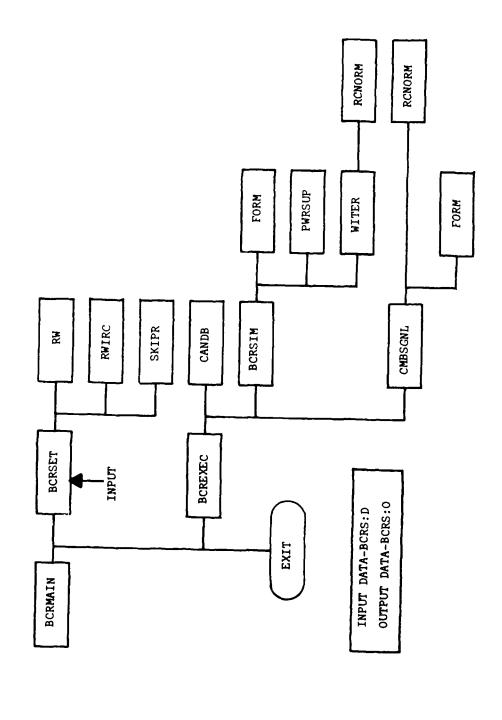


Figure 2-5. Tree Diagram of the BCR Simulation Program, BCRS

FORTRAN Listing of Source Modules Comprising the BCR Simulation Program, BCRS:S Table 2-14.

BREEFFERFERFERFERFERFERFERFERFERFERFERFER	PROGMAM: BCRMAIN:S URIGINAL: JULY 23. 1980 REVISION: AUGUST 12. 1980 REVISION: S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOWOLA GOVERNMENT ELECTHONICS DIV. TEMPE. ARIZONA 852H2	CALL BCRSET CALL BCRSET CALL BCREXEC CALL EXIT
0000000		U
- N M + N M - C	0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 -	17. 18. 19. 20. 21.

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SURGOUTINE ACRSET C SECRETARIES SERVINE C SPECIFICATION OF SYSTEM PARAMETERS: C PROGRAM : BCRSET:S C PROGRAM : BCRSET:S C PROGRAM : BCRSET:S C PREPARED RY : S. M. DANIEL & I. KERTE C PREPARED RY : S. M. DANIEL & I. KERTE C DOUTDUT : DATA FILE RCRSP:U C OUTDUT : RCRSP:U C OUTDUT : RCRSP:U C OUTDUT : RCRSP:U C OUTDUT : RCRSP:U C OUTDUT : RCRSP:U C OUTDUT : RCRSP:U C OUTDUT : RCRSP	C	SURGOUTINE ACKSET C	C SURQUITINE HCKSET C SPECIFICATION OF SYSTEM PRABETERS: C WAIN-PORT AND AUXILIARY BASEHAND SIGNALS C DRIGINAL : JULY 23, 1940 C CORPORT OF STRENG ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND ACCOUNTY I DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C C C C C C C C C C C C C C C C C C C	C	C SURQUITINE HCKSET C SPECIFICATION OF SYSTEM PRABETERS: C WAIN-PORT AND AUXILIARY BASEHAND SIGNALS C DRIGINAL : JULY 23, 1940 C CORPORT OF STRENG ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND ACCOUNTY I DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C C C C C C C C C C C C C C C C C C C	SURGOUTINE ACKSET C	SURGOUTINE ACKSET C	SURGOUTINE ACKSET C	SURGOUTINE ACKSET C	C SURQUITINE HCKSET C SPECIFICATION OF SYSTEM PRABETERS: C WAIN-PORT AND AUXILIARY BASEHAND SIGNALS C DRIGINAL : JULY 23, 1940 C CORPORT OF STRENG ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND ACCOUNTY I DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C C C C C C C C C C C C C C C C C C C	C SURQUITINE HCKSET C SPECIFICATION OF SYSTEM PRABETERS: C WAIN-PORT AND AUXILIARY BASEHAND SIGNALS C DRIGINAL : JULY 23, 1940 C CORPORT OF STRENG ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND SYSTEMS ANALYSIS GRAND ACCOUNTY I DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C OUTDIT : DATA FILE RCRSP:U C C C C C C C C C C C C C C C C C C C		C	C	C
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FORMAT(112A4,+E13.6) 300 FORMAT(1844,+X*,1012)	SURGOUTINE ACREST SPECIFICATION OF SYSTEM PARAMETERS: C SPECIFICATION OF SYSTEM PARAMETERS: C PROGRAM : RCRSET:S C ORIGINAL : JULY 23, 1940 C CRIGINAL : JULY 23, 1940 C CRIGINAL : JANUARY 24, 1981 C CRIGINAL : JANUARY 24, 1981 C OUTPUT : DATA FILE RCPSP:U C OUTPUT : DATA FILE BCRSP:O C OWDLEX CDUM, SI, SO C COMMON /BCRN / SI, SI, CS6, 20), NSX, NS COMMON /BCRN / SI, CS6, SI, CS6, 20), NSX, NS COMMON /BCRN / SI, CS6, SI, CS6, 20), NSX, NS COMMON /BCRN / SI, CS6,	SURGOUTINE ACREST SPECIFICATION OF SYSTEM PARAMETERS: C SPECIFICATION OF SYSTEM PARAMETERS: C PROGRAM : RCRSET:S C ORIGINAL : JULY 23, 1940 C CRIGINAL : JULY 23, 1940 C CRIGINAL : JANUARY 24, 1981 C CRIGINAL : JANUARY 24, 1981 C OUTPUT : DATA FILE RCPSP:U C OUTPUT : DATA FILE BCRSP:O C OWDLEX CDUM, SI, SO C COMMON /BCRN / SI, SI, CS6, 20), NSX, NS COMMON /BCRN / SI, CS6, SI, CS6, 20), NSX, NS COMMON /BCRN / SI, CS6, SI, CS6, 20), NSX, NS COMMON /BCRN / SI, CS6,	SURGOUTINE ACREST 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COMMON /BCRN / SI, CS6,	SURGOUTINE ACRSET C ===================================	SURGOUTINE ACREST SPECIFICATION OF SYSTEM PARAMETERS: C SPECIFICATION OF SYSTEM PARAMETERS: C PROGRAM : RCRSET:S C ORIGINAL : JULY 23, 1940 C CRIGINAL : JULY 23, 1940 C CRIGINAL : JANUARY 24, 1981 C CRIGINAL : JANUARY 24, 1981 C OUTPUT : DATA FILE RCPSP:U C OUTPUT : DATA FILE BCRSP:O C OWDLEX CDUM, SI, SO C COMMON /BCRN / SI, SI, CS6, 20), NSX, NS COMMON /BCRN / SI, CS6, SI, CS6, 20), NSX, NS COMMON /BCRN / SI, CS6, SI, CS6, 20), NSX, NS COMMON /BCRN / SI, CS6,	SURGOUTINE ACREST SPECIFICATION OF SYSTEM PARAMETERS: C SPECIFICATION OF SYSTEM PARAMETERS: C PROGRAM : RCRSET:S C ORIGINAL : JULY 23, 1940 C CRIGINAL : JULY 23, 1940 C CRIGINAL : JANUARY 24, 1981 C CRIGINAL : JANUARY 24, 1981 C OUTPUT : DATA FILE RCPSP:U C OUTPUT : DATA FILE BCRSP:O C OWDLEX CDUM, SI, SO C COMMON /BCRN / SI, SI, CS6, 20), NSX, NS COMMON /BCRN / SI, CS6, SI, CS6, 20), NSX, NS COMMON /BCRN / SI, CS6, SI, CS6, 20), NSX, NS COMMON /BCRN / SI, CS6,	SURGOUTINE ACREST SPECIFICATION OF SYSTEM PARAMETERS: C SPECIFICATION OF SYSTEM PARAMETERS: C PROGRAM : BCRSET:S C ORIGINAL : JULY 23, 1940 C CRIGINAL : JULY 23, 1940 C CRIGINAL : JANUARY 24, 1981 C DRIGINAL : JANUARY 24, 1981 C OUTPUT : DATA FILE BCRSP:0 C OUTPUT : DATA FILE BCRSP:0 C OUTPUT : DATA FILE BCRSP:0 C OWDULEX CDUM-S1+S0 C OWMON /BCRD/ INS0-1WS1-1WCR COMMON /BCRD/ INS0-1WS1-1WCR COMMON /BCRD/ INS0-1WS1-1WCR COMMON /BCRD/ ISP(20)+NWX-1WU-NPM1-ITERX DIMENSION ISC(20)+ISP(20)+AR12(12) 200 FORMAT(112A4+AX+1012) 200 FORMAT(112A4+E13+6) 300 FORMAT(1844+AX+1012)	SURGOUTINE ACRSET C SPECIFICATION OF SYSTEM PARAMETERS: C PROGRAM : BCRSET:S C ORIGINAL : JULY 23, 1940 C REVISION : JANUARY 24, 1981 C REPARED RY : S, M, DANIEL & I, KERTE RADAR SYSTEMS ANALYSIS GE MOTHOUT : DATA FILE BCRSP:0 C OUJPULT : DATA FILE BCRSP:0 C OUJPULT : DATA FILE BCRSP:0 C OUJPULT : DATA FILE BCRSP:0 C OWNON /BCRD/ INSO, IWS) + IWO, NOW ITERX DIMENSION /BCRD/ INSO, IWS) + IWO, NOW ITERX DIMENSION 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READ IN CHANNEL SELECTOR ARRAY AND ASSOCIATED CHANNEL DESCRIPTIONS
                                                                                                                                                                           READ IN PORT SELECTOR ARRAY AND ASSOCIATED PORT DESCRIPTIONS
                                                                                                                                                                                                                                                                                                                                                                                                          READ (105-100) ARI4+(ISW(IW)+IWENNI+NW2)
            ARIGA (ISM(IW) . IMENWI .NWZ)
                                                                                                                                                                                                                                               WRITE(108+100) AH14+(ISC(IC)+IC=NC1+NC2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            READ (105.100) AH14. (ISP(IP). IPENP1.NP2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          ARI4. (ISP(IP).IP=NP1.NP2)
                                                                                                                                                                                                                                READ(105,100) AR14. (ISC(IC). IC=NC1,NC2)
                                                                    IF (NWZ.GE.NWX) NWZENWX ; GOTO 1000
                                                                                                                                                                                      CALL PWINC (CDUM. NUM. NCHNLS. U)
                                                                                                                                                                                                                                                                                                                                                                                                                                                   CALL PEINCICHUM.KDUM.NPOHTS.0)
                                                                                   CALL PWINC(COUM.ROUM.ITERX.0)
                                                                                                                                                                                                                                                                                                       NCZ=NCHNLS
                                                                                                               RWINC (COUM+RDUM+NPOL+0)
                                                                                                                                                                                                                                                                                        IF (NC1.6T.NCHWLS) GUTO 2500
IF (NC2.6E.NCHNLS) NC2=NCHNL
                                                                                                                                                                                                                                                                                                                                                                                          CALL PHINC (COUM.HDUM.NS.0)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   IF (NP1.6T.NPM1) 60T0 3500
                                                       IF (NW1.6T.NWX) GOTO 1500
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  IF (NP2.6E.NPM1) NFZHNFM1
                                                                                                                                                                                                                                                                                                                                                              ICS(III=ICSUM+ISC(IC)
                                                                                                                                                                                                                                                                                                                                                                            CALL PW(4+H*ICSUM)
                                                                                                                                                                                                                                                                                                                                                DO 30 ICHI NCHNLS
                                                                                                                              CALL RW (NPOL+11)
             441TE (108.100)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          WATTE (108,100)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                   NDM1 HNPORTS-1
                                                                                                  CALL PW(20)
                                         NESHNES+10
                            CT+TEZHTEZ
                                                                                                                                                                                                                                                              NC1=NC1+10
                                                                                                                                                                                                                                                                            NC2=NCS+10
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        NP ] =NP [+10
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                                                                                                                                                                                                                                                                                                                                   ICSUM=0
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C. Progravy

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	IPSUMED 00 50 IP=1.NPM1 IPIW=1SP(IP)*ISW(IP) IF(IPIW*NF.ISW(IP)) 60T0 IPSUM=IPSUM+ISP(IP) CALL PW(7*(IPSUM+1))	READ IN MAIN AND AUXILIARY BASEBAND SIGNALS	IF(IWS0.EQ.0) GOTO 4000 READ AND WRITE SO	CALL RW(7) READ (105,200) AR12,5MAX WRITE(108,200) AR12,5MAX CALL RW(1) READ (105,300) (S0(IS),1S=1,NS) WRITE(108,300) (S0(IS),1S=1,NS) GOTO 4500	READ RUT DO NO CALL SKIPR (105 READ (105,200)	CALL SKIPR(105+1) READ (105+300) (SO(IS)+IS=1+NS) DENORMALIZE SO	- 0.	THE DESIGNATED PORTS SELECTED BY I	ITP=0 NROWS=(NS-1)/4+1 On qo IP=1*NPM1 IF(ISP(IP),EQ.0) GOTO HU IF(ISP(IP),EQ.0) GOTO 5000
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ī	200	SUBMOUTINE MAIN												
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s u		PRUGRAM	Ξ			RWIS								
U		ORIGINAL	٦¥٢		••	APHI	19	• 19	18					
u		REVISION	N O		••	JUNE 15, 1980	15	• 19	1980					
		PHEPARED	₹ 0	8	••	S. R	, OA	NIEL	•	-	A R	TES	•	
						RADA	A SY	STEM	SAN	ALY	515	GROU	JP SNTCS	RADAM SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT FLECTRONICS DIV.
		!				TEMP	4	TEMPE, ARIZUNA 85282	4	852	32			
~	ZPU1	INPUT :			,	NUMB	3		NES	0	36	EAD	A S	NUMBER OF LINES TO BE READ AND WRITTEN
# C	MENS	тицияний и и и и и и и и и и и и и и и и и и	(20) (20)	N H N	;; # #	## P# P# 00	H H H	 1 1 1 1 1	H H H H	ii R N	N H H	N N N	H W W	H H H H
100 F	DRMAT	FORMAT (20A4)												
	01 0	00 10 Imlen												
æ	EAD ()	105,100	AR	0										
10 1	RITE (108.100	AK	0										
	ETURN	RETURN												
ũ	END													

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CONSISTING OF A 56-CHARACTER COMPENT C A COMPLEX, REAL ON INTEGER SCALAR VARIABLE VALUE PHUGBAM : RAIRCIS C CRIGINAL : APRIL 19, 1960 REVISION : AUGUST 13, 1960 REVISION : AUGUST 13, 1960 C INPUT : IND OPTION INDICATOR C OUTPUT : IND OPTION INDICATOR C OUTPUT : CX - COMPLEX SCALAR EXCLUSIVE OF RX & IX REAL SCALAR EXCLUSIVE OF RX & IX C COMPLEX CA C COMPLEX CA INTEGER SCALAR EXCLUSIVE OF CX & IX C COMPLEX CA C COMPLEX SCALAR EXCLUSIVE OF CX & IX REAL SCALAR EXCLUSIVE OF CX & IX C COMPLEX CA C COMPLEX SCALAR EXCLUSIVE OF CX & IX REAL SCALAR EXCLUSIVE OF CX & IX C C COMPLEX CA C C C C C C C C C C C C C C C C C C		INWEST SERVICE THE SERVICE OF THE SERVICE SERV
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A COMPLEX, REAL ON INTEGER SCALAR VARIABLE VALUE PHUGRAM I RVIRCIS ORIGINAL I APHIL 19, 1980 C ORIGINAL I APHIL 19, 1980 REVISION I AUGUST 13, 1980 C IMPUT I IND - OPTION INDICATOR C IMPUT I IND C IMPU		A JOHN THE CONTRACT OF A
C PRUGRAM : RWIRCIS C ORIGINAL : APRIL 19. 1980 C C REVISION : AUGUST 13. 1980 C C RANDEL E I. KERTESZ RADARA SYSTEMS ANALYSIS GROUP MOTOROUA GOVERNMENT ELECTRONICS DIV. TEMPE, ARIZONA 85282 C INPUT : IND	. U (A COMPLEX. REAL OM INTEGEM SCALAR VARIABLE VALUE
C ONTECNAL : APHIL 19, 1980 C PREVISION : AUGUST 13, 1980 C PREPARED BY : S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP HOTOLA GOVERNMENT ELECTRONICS DIV. C INPUT : IND - OPTION INDICATOR C INPUT : IND - OPTION INDICATOR C OUTPUT : CX - COMPLEX SCALAR EXCLUSIVE OF CX & IX I HEAD & WRITE COMPLEX C COMPLEX CX DIMENSION AH14(14) 100 FORMAT(14A4.112.5) 200 FORMAT(14A4.12.5) 200 FORMAT(14A4.12.5) 300 FORMAT(14A4.13.5) 300 FORMAT(14A4.13.5) 300 FORMAT(14A4.13.5) 300 FORMAT(14A4.14.5) 300 FORMAT(14A4.13.5) 300 FORMAT(14A4.13.5	ی د	•
REVISION 1 AUGUST 13, 1980	, u	APRIL 19.
C PREPARED BY : S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNHENT ELECTRONICS DIV. TEMPE. ARIZONA 85282 C INPUT : IND - OPTION INDICATOR C INPUT : IND - OPTION INDICATOR C OUTPUT : 'CX - COMPLEX SCALAR EXCLUSIVE OF RX & IX C COMPLEX CX DIMENSION AMIA(14) 100 FORMAT(14A4-112) 200 FORMAT(14A4-112) 300 FORMAT(14A4-112) 400 FORMAT(1AA4-112) 400 FORMAT(1AA4-112) 400 FORMAT(1AA4-112)	· U	1 AUGUST 13.
## PADAR SYSTEMS ANALYSIS GROUP ## PADAR SYSTEMS ANALYSIS GROUP ## PADAR SYSTEMS ANALYSIS GROUP ## PADAR SYSTEMS ANALYSIS GROUP ## PED ## PADAR SYSTEMS ANALYSIS GROUP ## PED ## PE	טע	T 4 DANTEL F
MOTOROLA GOVERNMENT ELECTRONICS DIV. C		-
C INPUT : IND - OPTION INDICATOR C OUTPUT : IND - OPTION INDICATOR 1 : HEAD & WHITE HEAL 2 : HEAD & WHITE COMPLEX C COMPLEX SCALAR EXCLUSIVE OF RX & IX C COMPLEX CX C C C C C C CX C C C C CX C C C C		MOTOROLA GOVERNMENT ELECTRONICS DIV. TEMPE, ARIZONA 85282
C OUTPUT : 'CX - COMPLEX COMPLEX C OUTPUT : 'CX - COMPLEX SCALAR EXCLUSIVE OF RX & IX C OUTPUT : 'CX - COMPLEX SCALAR EXCLUSIVE OF RX & IX C MALENSTERRESSERVENCES SCALAR EXCLUSIVE OF CX & IX C MALENS CANDER CANDE		
		O : WEAD 6 WRITE
C OUTPUT 1 'CX - COMPLEX SCALAR EXCLUSIVE OF RX & IX C		S HEAD & WHITE
C OUTPUT : 'CX - COMPLEX SCALAR EXCLUSIVE OF RX & IX C IX - REAL SCALAR EXCLUSIVE OF CX & IX C MATERIAL MATERIA		I HEAD & WRITE
C STREET		A XO BO BUTCH DXB BAILDS X3 IGNOT A X7.
C BEREEFERENCE ENTERENCE E		HX - REAL SCALAR EXCLUSIVE OF CX 6. IX
C SERTERERERERERERERERERERERERERERERERERER	·U	F CX 6
9000	U	
0000 0000 0000 0000		DIMENSION ARIA (14)
300		FORMAT (144+112)
300	200	FORMAT (1444+F12-5)
GOTO (1,2), IND READ (105,100) WRITE(108,100) RETURN RETURN 2 READ (105,200) RETURN RETURN END RETURN END		FORMAT (1444.2X,2(F10.5))
READ (105,100) WRITE(108,100) RETURN WRITE(108,200) RETURN Z READ (105,300) RETURN END		
WRITE(108,100) RETURN READ (105,200) WRITE(108,200) RETURN RETURN RETURN RETURN END		
1 READ (105,200) WRITE(108,200) RETURN RETURN WRITE(108,300) RETURN		1001-801
MRITE(108,200) RETURN RETURN WRITE(108,300) RETURN END	-	105.2001
Z READ (105+300) WRITE(108+300) RETURN END	•	-
WAITE (108,300) RETURN END		-
END		

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	SKIP	NS LIN	SKIP NS LINES ON UNIT NU-			PRESENTABLE RESERVE STREET STR
			PROGRAM OPIGINAL REVISION	1 2		SKIPRIS February 23. 1981 February 23. 1981
9. 110. 113. 13. 13.			PREPARED	9 *	••	S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS DIV. TEMPE, ARIZONA 85282
16.	Ž	INPUT	SS			NUMBER OF UNIT OR DEVICE NUMBER OF LINES TO SKIP
	00	OUTPUT :	••		•	1
20. 21. 21.	EN.	ENTRY POINTS SUBROUTINES	ENTRY POINTS SUBROUTINES CALLED	LED		SKIPA
23. 100 24. C.	0 50	FORMAT (1X)	(X)	20 10 10 10 10 10	H H H	
25.	SK	SN dI	SKIP NS LINES ON UNIT NU	Z CNI	Ş	ON LIN
27. 28. 10. 30.		AD IN THE PROPERTY OF THE PROP	00 10 1#1.NS READ(NU.100) RETURN END			

A TABLE Y

 	C BREEFERENCH INC SCREXE	
ب	16	
•	C BCR FXECUTION PROGRAM	
	C PROGRAM : BCREXECIS	
	••	
8	••	
• •	C POFPARFO BY : S.M. DANIFL & I. KERTESZ	
11.		
12.	C MOTOROLA GOVERNMENT ELECTRONICS DIV.	
13.	C TEMPE, ARIZONA A5282	
14.		H
15.	COMPLEX SO.SI.C.B.R.P.CP.44.SC.WII	
16.	COMMON / BCRO/ INSO+INSI+INCB	
17.	COMMON /BCR1/ S0(256).S1(256,20).NSX.NS	
18.	COMMON /BCR2/ ISE(20).NEX.IBO.NPMI.IIERX	
19.	COMMON /BCR3/ W(20).SC(256).wIT(21.20)	
20.	DIMENSION C(20,20),8(20),R(20),P(20)	
21.	CALL CANDS (SO.SI.C.B.CMAX.BMAX.PO.NSX.NS.NEX.NPMI.IECS)	
22.	ITERA1=17FRX+1	
23.	CALL BCRSIM(C+B+R+P+CP+W+WIT+CMAX+BMAX+PO+IWU+NWX+NPMI+ITERX	
24.	1 TERX 1)	
25.	CALL CMBSGNL(SO.SI.W.SC.CMAX.AMAX.NSX.NS.NPMI)	
26.	えなつといる	
27.	CZU	

V-93

**************************************	DO 10 IS=1.NS PO=PU+CABS(SO(IS)) **2	INITIALIZE C AND B TO ZERU	Un 20 IP=1,NPM1 H(IP)=U Un 20 JP=1,NPM1	COMPUTE C AND B FOR SELECTED PORTS	00 30 IS=1.NS 00 30 IP=1.NPM1 CS1=CONJG(S1(IS.IP)) B(IP)=B(IP)+CS1=S0(IS) D0 30 JP=1.NPM1 C(ID_1D)=C(IP_1D)+CS1=S0(IS)	CONTINUE CONTINUE NORMALIZE C AND 8 INDEPENDENTLY	CMAKABMAXAU DO 40 IPB1,NPM1 ARSXABS(REAL(C(IP,IP))) IF(ARSX.GT.CMAX) CMAXABSX ARSXABUS(AIMAG(C(IP,IP))) IF(ARSX.GT.CMAX) CMAXABSX ARSXABUS(REAL(B(IP))) IF(ARSX.GT.CMAX) BMAXEABSX ARSXABS(REAL(B(IP))) IF(ARSX.GT.CMAX) BMAXEABSX ARSXABS(AIMAG(B(IP)))	IF (ABSX.GT.BMAX) BMAX=ABSX DO 50 IP=1.NPM1 B(IP)=B(IP) +BMAX DO 50 JP=1.NPM1 C(IP-JP)=C(IP-JP)/CMAX	
P080		INITI		COMPUT		30 CONTIN			GFT 0P

- 0 6		SUBROU!	SUBPOUTINE BCRSIM	(C+8+R+	SUBPOUTINE BCRSIM(C.B.R.P.CP.W.WIT.CMAX.BMAX.PO.IWO.NWX.NPWIITERX.ITERX.
, v			EST	ESTIMATION OF	ESTIMATION OF ADAPTIVE WEIGHT VECTOR VIA BCR SIMULATION
	,,,,,,,,,		PROGRAM ORIGINAL REVISION		BCRSIM:S APRIL 15. 1978 FEBRUARY 27. 1981
16.19.	နှပ်ပုပ္ပ		PREPARED	. ≻	S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS DIV. TEMPE, ARIZONA 85282
18.		INPUT	0		COVARIANCE MATRIX OF AUXILIARY SIGNAL
20.	. U (œ	•	
22.	ی ز		9	•	auxiliary signals Main-Port signal power
23.	U (CHAX	•	CONSTANT
25.	ں ب		Y ORI	• •	NORMALIZATION CONSTANT FOR B WEIGHT VECTOD INITIALIZATION THOICATOD
26.	O C		•		O 1 SETS INTITIAL W 10 SERO
28.	υ		X	•	A TOURS PREVIOUS W VALUE MAXIMUM NUMBER OF WEIGHTS
29.	U (ITERX	•	9
30.	U U		ITERXI		MAXIMUM NUMBER OF ITERATIONS PLUS ONE
32.	· U		•)	SOURCE OF MONICIANT PORTS
33.	U	- 1	>	•	ADAPTIVE WEIGHT VECTOR
35. 36.		Ħ	MANGEMENT OF THE STATE OF THE S	· W·CAR	MERMENNERMENTERMENTERMENTERMENTERMENTERMENTERMENTERMENTERMENTERMENTERMENTERMENTERMENTERMENTERMENTERMENTERMENTERMENTERMENTERMENSION C(NWX+1)+BARRANTERMENTERM
37.	•	IARR (1	· IARR(1) • WIT(ITERX1 • 1)	1.1)	
30.	999	FORMAT (1H1)	FORMAT (1H1) FORMAT (1K-100(1-1))		
• 0 •	300	FORMAT	FORMAT(41X.PERFORMANCE SUMMARY OF	MANCE	WINNARY OF BCD STALL ATTOMS / ALX 227 (22)
41.	004	FORMAT (2X. INITIAL	CONDI	
42.	200	FORMAT (/ 2X,	1/2×4, C		1 * 8F10.5*/
•?•		- (28X - 8F 10 - 5)	F10.5))		

10N OVER SELECTED PORTS 00) 00) 00) 00) 00) 00) 00) 00) 00) 0	900	/.(28x.8F10.5)) CESS'./.2x.12('	
WRITE(106-100) WRITE(106-200) WRITE(-	BCR SIMULATION OVER SELECTED PORTS	
INITIAL BCR CONDITIONS BDB=ROR=WDW=ITER=0 IF (IMO.EQ.1) 60TO 1000 DO 10 IF=1.NPM1 W(IP)=8 (IP) DO 30 JP=1.NPM1 R(IP)=8 (IP)=8 (IP) DO 30 JP=1.NPM1 R(IP)=8 (IP)=8 (IP) DO 30 JP=1.NPM1 R(IP)=8 (IP)=8 (IP) DO 40 IP=2.NPM1 WRITE (108.600) (C(IP.JP).JP=1.NPM1) CALL FORM (* B NORM ** RARR.IARR.NPM1.0.1) CALL FORM (* R NORM ** RARR.IARR.NPM1.0.2) RARR(I)=RORM (* R NORM ** RARR.IARR.NPM1.0.2) RARR(I)=ROBBH CALL FORM (* R NORM ** RARR.IARR.NPM1.0.2) RARR(I)=ROBBH CALL FORM (* R NORM ** RARR.IARR.NPM1.0.2) RARR(I)=ROBBH CALL FORM (* R NORM ** RARR.IARR.NPM1.0.2)		WRITE(108,100) WRITE(108,200) WRITE(108,300) WRITE(108,200)	
### ##################################		INITIAL BCR CONDITIONS	
W(IP)=0 DO 20 IP=1.NPM] R(IP)=B(IP) DO 30 JP=1.NPM] R(IP)=B(IP) R(IP)=R(IP)+C(IP-JP)=W(JP) R(IP)=R(IP)=R(IP) R(IP)=R(IP) R(IP)=R(IP) R(IP)=R(IP) R(IP)=R(IP) ROB=BDB-CABS(R(IP))=*2 ROB=BDB-CABS(R(IP))=*2 ROB=BDB-CABS(R(IP))=*2 ROB=BDB-CABS(R(IP))=*2 ROB=BDB-CABS(R(IP))=*2 ROB=BDB-CABS(R(IP))=*2 ROB=BDB-CABS(R(IP))=*2 ROB=BDB-CABS(R(IP))=*2 ROB=BDB-CABS(R(IP))=*2 ROB=BDB-CABS(R(IP))=*3 RAR(I)=RNORM CALL FORM(* B RAR(I)=RNORM CALL FORM(* RNORM CALL FORM(* RNORM CALL FORM(* RNORM RAR(I)=RNORM CALL FORM(* RNORM) RARR(I)=RNORM(* RNORM)		BOBERDREWDWEITERED IF(INO.EQ.1) GOTO 1000 DO 10 IPE1.NPM1	
R(IP)=B(IP) DO 20 IP=1.NPHI R(IP)=B(IP) DO 30 JP=1.NPHI R(IP)=R(IP)+C(IP,JP)=W(JP) R(IP)=R(IP) BDB=BDB-CABS(R(IP))==2 BDB=BDB-CABS(R(IP))==2 BDB=BDB-CABS(R(IP))==2 BDB=BDB-CABS(R(IP))==2 BDB=BDB-CABS(R(IP))==2 BDB=BDB-CABS(R(IP))==2 BDB=BDB-CABS(R(IP))==2 BDB=BDB-CABS(R(IP))==2 BDB=BDB-CABS(R(IP))==2 BDB=BDB-CABS(R(IP))==2 BDB=BDB-CABS(R(IP))==3 BRATE(108-500) (C(11-JP)-JP=1-NPHI) DO 40 IP=2-NPHI WRITE(108-500) (C(11-JP)-JP=1-NPHI)) CALL FORM(* BRATE(1)=BNORM* CALL FORM(* RAPR(1)=RNORM* CALL FORM(* RNORM* CALL FORM(* RN	10	0= (dI) A	
R(IP) =R(IP) +C(IP,JP) +W(JP) BDB=BDB+CABS(B(IP)) ++-2 ROR=ROR+CABS(W(IP)) ++-2 BNORM=SQRT(BDB) RNORM=SQRT(RDB) WNORM=SQRT(RDB) WNORM=SQRT(RDB) WNORM=SQRT(RDB) ROB=ROR-GOR ROB=ROR-GOR RAPITE(108+500) (C(IP,JP),JP=1,NPM1) DO 40 IP=2+NPM1 WRITE(108+500) (C(IP,JP),JP=1+NPM1) CALL FORM(* BNORM CALL FORM(* R RARR(1) =RNORM CALL FORM(* R RARR(1) =RNORM CALL FORM(* R RARR(1) =RNORM		R(IP) = B(IP)	
### ##################################	30	R(IP) =R(IP) +C(IP+JP) +W(JP)	
WDW=WDW+CABS(W(IP))++2 BNORM=SQRT(BDB) RNORM=SQRT(RDR) WNORM=SQRT(RDR) WNORM=SQRT(RDR) ROB=RDR/BDB ROB=RDR/BDB ROB=RDR/BDB ROB=RDR/BDB ROB=RDR/BDB ROB=RDR/BDB ROB=RDR/BDB ROB=RDR/BDB RATTE(108+500) (C(1+JP)+JP=1+NPM1) DO 40 IP=2+NPM1 WRITE(108+500) (C(1P+JP)+JP=1+NPM1) CALL FORM(* B) RARR(1)=BNORM CALL FORM(* R) RARR(1)=RNORM CALL FORM(* R) RARR(1)=RNORM CALL FORM(* R) RARR(1)=RNORM		F(IF/BX(IF) BDB=BDB+CABS(B(IF))++2 BDB=BDB+CABS(B(IF))++2	
RNORM=SGRT (RDR) WNORM=SGRT (RDR) WNORM=SGRT (WDW) ROB==100 IF (ROB.6T.1.0E-10) ROBDB=10*ALOG10 (ROB WRITE (108.500) (C(1.JP).JP=1.NPM1) DO 40 IP=2.NPM1 WRITE (108.600) (C(IP.JP).JP=1.NPM1) CALL FORM(' B RARR(1)=BNORM CALL FORM(' R RARR(1)=RNORM CALL FORM(' R RARR(1)=ROBDB CALL FORM(' R) RARR(1)=ROBDB	20	WDWBWDW+CABS(W(IP)) **Z	
WNORM=SGRT(WDW) ROB=RDR/BDB ROBD=-100 IF(ROB.6T-1.0E-10) ROBDB=10*ALOG10(ROB WRITE(108.500) (C(1.JP).JP=1.NPM1) DO 40 IP=2.NPM1 WRITE(108.600) (C(IP.JP).JP=1.NPM1) CALL FORM(' B RARR(1)=BNORM CALL FORM(' R RARR(1)=RNORM CALL FORM(' R RARR(1)=ROBDB CALL FORM(' R RARR(1)=ROBDB		ANONH (ADA)	
### ### ##############################		WOORMESORY (WOW)	
WRITE(108-400) WRITE(108-500) (C(1-JP),JP=1-NPM1) DO 40 IP=2-NPM1 WRITE(108-600) (C(IP-JP),JP=1-NPM1) CALL FORM(' 8 RARR(1)=RNORM CALL FORM(' R RARR(1)=RNORM CALL FORM(' R RARR(1)=RNORM CALL FORM(' R RARR(1)=ROBDB CALL FORM(' R		RABDB==100 IF(ROB.6T.1.0E=10) ROBDB=10*ALOG10(RO	
WRITE(108,500) (C(1,JP),JP=1,NPH1) DO 40 IP=2,NPH1 WRITE(108,600) (C(IP,JP),JP=1,MPH1) CALL FORM(* 8 RARR(1)=8NORM CALL FORM(* R RARR(1)=RNORM CALL FORM(* R RARR(1)=RNORM CALL FORM(* R RARR(1)=RNORM CALL FORM(* R)		WRITE (108,400)	
WRITE(108.600) (C(IP.JP),JP=1.MPH1) CALL FORM(* B RARR(1)=BNORM CALL FORM(* R RARR(1)=RNORM CALL FORM(* R RARR(1)=RNORM CALL FORM(* RNORM CALL FORM(* RNORM CALL FORM(* RNORM		_	
CALL FORM(* B RARR(1) #BNORM CALL FORM(* R RARR(1) #RNORM CALL FORM(* RNORM RARR(1) #ROBOB CALL FORM(* P	•	→	
(1) #BNORM FORM(* 8NORM FORM(* R (1) #RNORM FORM(* RNORM (1) #ROBDB)		1 . B. RARR, IARR, NPM1 . 1 . 2)
TOKE TOKE		I) =BNORM	
(1) #RNORM FORM (* RNORM (1) #ROBOB		FORM	: * • CARM• MARR• [ARR• [•0•1]
FORM(* RNORM (1) #ROBOB FORM(* P		(1) =RNORM	/3-0-11-12-14-14-14-14-14-14-14-14-14-14-14-14-14-
(1) =R0B0B FORM(* P		FORM (: . CARR, RARR, IARR, 1.0.1)
		(1) #R0808	
		FORM C.	* * P * RARR * I ARR * NPM1 * 0 * 2)

```
1 . CP . RARR . I ARR . NPM1 . 0 . 2)
     PWRSUP(8+R+W+CMAX+8MAX+PO+POC+NPM1)
                                                                                                                                                                                                                                                                                                                                                                                                     1 . CARR, RARR, IARR, 1, 1.0)
                                                                                                                                                                                                                                                                                                                                                                                                                                        : * . CARR . RARR . I ARR . 1 . 0 . 1 )
                                                                                                                                                                                                                                                                                                                                                                                                                                                              : * . CARR . RARR . IARR . 1 . 0 . 1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                         1 * . W . RARR . I ARR . NPM1 , 0 . 2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                1 . CARR. RARR. IARR. 1,0.1)
                                             : " . CARR . POC . IARR . 1 . 0 . 1)
                                                                                                        CALL WITER(W.WIT.CMAX.BMAX.ITERXI,NPMI.1WO.ITER.O)
                                                                                                                                                                                                                                                                                                                                           F (ROB.GT.1.0E-10) ROBDB=10*ALOG10(ROB)
                                                                                                                                                                                      PCP*PCP+REAL (CONJG(P(IP)) +CP(IP))
                                                                                                                                                                           CP(IP) #CP(IP) +C(IP+JP) +P(JP)
                                                                                                                                                                                                                                                            R (1P) =R (1P) -ALPHA • CP (1P)
                                                                                                                                                                                                                                                H(IP) =H(IP) - VFHY + P(IP)
                                                                                                                                                                                                                                                                       RORERDR+CABS(R(IP))++2
WDWEWDW+CABS(W(IP))++2
                                             (08)
                                                                                                                                                                                                                                                                                                                                                                              P(IP) =R(IP) +BETA*P(IP)
           CALL FORM (* WNORM
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   INCOR
                                                                                                                                                                                                                                                                                                                                                                                                                                                                ALPHA
                                                                                                                                                                                                                                                                                                                                                                                                     ITER
                                             CALL FORM (* POC
                                                                                                                                                                                                                                                                                                                                                                                                                                       a
3
4
                                                                                            MAIN BCR PROCESS
                                                                                                                                                                                                                                                                                                                                                                                                                  <u>ی</u>
                                                                                                                                                                                                                                                                                                         WNORM=SORT (NDW)
                                                                                                                                                                                                                                                                                                                                                                   DO 80 IP=1.NPM1
                                                                                                                                         DO 50 IP=1.NPM1
                                                                                                                                                               DO 60 JP=1.NPM1
                                                                                                                                                                                                                                     DO 70 IP=1.NPM1
                                                                                                                                                                                                                                                                                              RNORM=SORT (RDR)
                                                          WRITE(108.700)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      RARR(1) =WNORM
                                                                                                                                                                                                  ALPHA = RDR / PCP
                                                                                                                                                                                                                                                                                                                                                         BETA#ROR/RORO
RARR(1)=ENORE
                                                                                                                                                                                                                                                                                                                                                                                                                                                    RARR(1)=ALPHA
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                       CALL PWRSUP
RARR(1)=POC
                                                                                                                                                                                                                                                                                                                                                                                                                             RARR(1) *PCP
                                                                                                                   ITER=ITER+1
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MOTUROLA GOVERNMENT ELECTRONICS DIV.
                                                                                                HADAR SYSTEMS ANALYSIS GOUUP
                                                                                        & I. KENTESZ
                                                                                                                                                                          SINGLE-LINE SKIP OPTION
                                       COMPLEX, REAL OR INTEGER ARRAYS
                                                                                                                 TEMPE. ARIZONA RSZUZ
                                                                                                                          INTEGER-VALUED ARRAY
                                                                                                                                                                  ARRAY DIMENSTONALITY
                                                                                                                                                                                                  ARRAY-TYPE INDICATOR
                                                                                                                                          COMPLEX-VALUED ARRAY
                       SPECIALLY-FORMATTED OUTPUT
                                                               15. 1978
                                                                       SEPTEMBER 13. 1980
                                                                                                                                                 REAL-VALUED ARRAY
                                                                                                                                 INENTIFYING LABEL
                                                                                                                                                                                  : NO SKIP
                                                                                                                                                                                                            INTEGER
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                                                                                        S. M. DANIEL
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WALTE (104+200) LABEL+(IX(I)+1=NX1+NX2)
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REVISION
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44. GOTO 1000
45. 1 WRITE(108.400) LABEL, (RX(I).I=NXI.NXZ)
46. GOTO 1000
47. 2 WRITE(108.400) LABEL.(CX(I).I=NXI.NXZ)
48. 1000 NXI=NXI.++
49. IF (NXI.6I.NX) RETURN
50. NXZ=NXZ++
51. GOTO (1,2.3.4.5).INDI
53. 3 WRITE(108.300) (IX(I).I=I.NXI.NXZ)
60TO 1000
54. WRITE(108.500) (RX(I).I=NXI.NXZ)
60TO 1000
55. 4 WRITE(108.500) (CX(I).I=NXI.NXZ)
60TO 1000
56. GOTO 1000
57. 5 WPITE(108.500) CX(I).I=NXI.NXZ)
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	ں ن	ā	PROGRAM	••	PWPSUP:S
8.	U	5	URIGINAL	••	SEPTEMBER 11. 1980
•	U G	፯	HEVISION	••	SEPTEMBER 12. 1980
	ا ن د	ā	PREPARED	BY :	S. M. DANIEL & I. KERTESZ
13.	υU				MADAH SYSIEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS DIV.
14.	C) L				TEMPF. APIZONA RS282
16.	ں ر	: TUPNI	æ	•	FORCING VECTOR
17. (U		α	•	RESIDUAL VECTOR
18.	U		3	•	ADAPTIVE WEIGHT VECTOR
	ပ		9 0	•	MAIN-PORT SIGNAL POWER
20.	U		CHAX	•	NORMALIZATION CONSTANT FOR C
21. (u		XVMT	•	FOR
22. (u ،		NPM1	•	NUMBER OF AUXILIARY PORTS
24.	u u				
25.	U	OUTPUT :	POC	•	MAIN/COMBINED SIGNAL POWER IN DH
26. 27.	ပ	HUNGHHUNGHUNGH SOMPLFX B.S.	# # # 3 # 2	94 97 94 44 91 91	化异苯酚酚医异丙酚酚酚酚医异丙酰胺甲酰胺甲酰胺甲酰胺甲酰甲酰甲甲酰甲甲酰甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲
28.		DIMENSION B(1) + R(1) + W(1)	B(1) • R	1) ** (1)	
29.		WRRMAX BMAX + + 2/CMAX	AX++2/CF	AX.	
30.			L MON		
	0	PCHPC+MBR	MAX*REAL	SCNOO)	PCHPC+WBRMAX*REAL(CONJG(W(IP))*(B(IP)+R(IP)))
	,	PC=4BS (PC)			
34.		POC=PC/P0			
35.		IF(POC.LT.1.0E-10) POC=1.0E-10	.1.0E-1() P0C=	1.0E-10
36. 37		POCE-10*ALOGIU(PUC)	. 0610 (P.	Ç	
36.		END			
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		ADAPTI	IVE WEI	CONTAINING ADAPTIVE WEIGHTS AT EACH BCR ITERATION
	-	PROGRAM	••	ZITER 3 S
000		ORIGINAL	••	SEPTEMBER 13. 1980
ပ (REVISION	•	56.
ى ر		PREPARED	BY :	S. M. DANIEL & I. KERTESZ BADAD SYSTEMS ANALYSTS GROUP
000				MOTOROLA GOVERNMENT ELECTRONICS DIV TEMPE. ARIZONA 85282
00	INPUT	*	•	ADAPTIVE WEIGHT VECTOR
. U (ITERXI	•	MAXIMUM NUMBER OF ITERATIONS PLUS ONE
، ن		KAMO	•	CONSTANT FOR
. .		X Y Z Z	• (NORMALIZATION CONSTANT FOR B
ں ر		INO	• •	WEIGHT VECTOR INITIALIZATION INDICATOR
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U (4450	(1 : USES PREVIOUS W VALUE
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U U				1 # ACR PROCESS COMPLETE
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•	COMPLEX WOWIT	LIBOR		
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•	.16x AD	16X ADAPTIVE WEIGHT	IGHT VE	VECTOR AT INDICATED BCR ITERATION
•	0N. 4X614	-119X+*NORMALIZATION CONSTANT	N CON	STANT : ".E13.6)
000	FORMAT (8F 10.5)	F 10.57	1	FORMATION 10.57

(WIT(IP, IT), IP=1,NPM1) IF(IWO.EQ.O.AND.ITER.EQ.O) GOTO 2000 CALL RCNORM(W.RARR.WMAX.NPM1.2.0) DO 10 IP=1.NPM1 (F (WMAX.GT.WITMAX) WITMAX=WMAX WIT(IP.II) =WIT(IP.II) /WITMAX IF (IND.EQ.1) GOTO 1000 IF(IND.EG.0) RETURN WSCL=WITMAX+BMAX/CMAX **MSCL** MIT (IP. ITI) MM (IP) WRITE(108.200) WRITE(108.300) WRITE(108.200) 00 20 IT=1,1T1 D0 20 IP=1,NPM1 MRITE (108.400) WRITE (108.100) DO 30 IT=1,IT1 WRITE (108,200) WITHAX=WMAX=0 IT1=ITER+1 RETURN 2000 10 1000 20 30 60. 62. 63. 65. 45. \$ 7.6 \$ 8.

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الأمستدانات عار

SERRESTERRESERRESERRESERRESERRESERRESER	PROGRAM : RCNORM:S ORIGINAL : AUGUST 31, 1980 REVISION : JANUARY 26, 1981	PREPAMED BY : S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTUROLA GOVERNMENT FLECTHONICS DIV. TEMPE. ARIZUNA 85282	INPUT: CX - COMPLEX ARRAY TO HE NUMALIZED RX - REAL ARRAY TO HE NORMALIZED NX - ARRAY DIMENSIONALITY IND - ARRAY-TYPE INDICATOR 1 : REAL 2 : COMPLEX	RMAL :	OUTPUT ? CX - NORMALIZED COMPLEX ARRAY RX - NORMALIZED REAL ARRAY XMAX - NORMALIZATION CONSTANT	COMPLEX CX DIMENSION CX(1).RX(1) FORMAT(" *** WARNING : YOU ARE NORMALIZING A NULL ARRAY ****)	, – – ;	XMAX=0 IF(IND.EQ.2) GOTO 1000 DO 10 I=1.NX ARSX=ABS(RX(I)) IF(ARSX.GT.XMAX=ABSX IF(XMAX.EQ.0) GOTO 9999 IF(IUPTN.EQ.0) RETURN DO 20 I=1.NX
0 000	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,		0000	, 66 C	,,,,,,	,
-0.64 u		132:		22. 23. 24.	25. 26.	29. 31.	36.4	

44. 20 RX(I)=RX(I)/XMAX
45. RETURN
47. RETURN
48. ARSX=ABS(REAL(CX(I)))
49. IF(ABSX.GT.XMAX) XMAX=ABSX
50. 30 IF(ABSX.GT.XMAX) XMAX=ABSX
51. IF(XMAX.EQ.0) RETURN
52. Dn 40 I=1.NX
54. 40 CX(I)=CX(I)/XMAX
55. C RETURN
56. 9999 WRITE(108.999)
57. STOP
59. END

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	-	SUBROUT 1	SUBROUTINE CABSONL (SO+S1+#+SC+	1 (50.51	· W · SC ·	NSX+NS+NPHI)
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9 0	, ر		3	•		11 VECTOR CHAX BHAX
20.) U		NSX	•	MAXIMON NUMBER	MAXIMUM NUMBER OF SIGNAL SAMPLES
23.	U		NS	•	ACTUAL NUMBER	NIJMBER OF SIGNAL SAMPLES
25.	U		NPMI	•	NUMBER OF AUX	ILIARY PORTS
23.	O,					
24.	ပ	OUTPUT :	25	•	COMBINED PORT SIGNAL	SIGNAL
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26.		COMPLEX	COMPLEX SO.SI.W.SC.CAXXOLMENSION SC.(1).SI.CNSX.	C.CARR 1 (NSX.)) + W (1) + SC (1) + C	COMPLEX SO+Si+We-SC+CARR DIMENSION SC(1)+S1(NSX+1)+E(1)+SC(1)+CARR(1)+RARR(1)+IARR(1)
28.	100	FORMAT (1H1)	(HI)			
29.	200	FORMAT	FORMAT (1X.79(*-+))			
30.	300	FORMAT	FORMAT (BOX - COMPINED	NEO POR	PORT ** / * 33X * 13(* - 1)	
31.	004	FORMATIC	SSX, *WECE!	IVED BAS	FORWAT(25%, MECEIVED BASEBAND FORT SIGNAL',/,19%	IAL 10/0197
36.	9	FORMAT (BE TO ST	2	2000	•	
• • • •		-	7 1000			
35.		COMPUTE	COMPUTE COMPINED PORT SIGNAL AND	PORT SI	GNAL AND ASSUC	ASSUCIATED POWER SUPPRESSION
36.	ا ن					
37.	ı	WMAX=FMAX/CMAX	NX/CMAX			
38.		FORPC#0				
36.		DO 10 15=1,NS	5#1 • NS			
• 0 •		13)	50 (1S)			
	0	SC (1S) #8	FE •NFE	15. IP) •	D)	
4 3	j	POSPO+C#	POSPO+CAHS(SO(15))++2	1 **2		

```
: . CARK. RARR. IARR. 1.0.1)
                IF (PC.NE.0) PCAN=10+ALUS10(P0/PC)
                                 CALL PCNORM(SC.RARH,SMAX,NS.2.1)
WPITE(108,100)
                                                                                            (SC(IS), IS*1,NS)
                                                                                                                      (90)
                                                                                                                     CALL FURM(* SUPPRESSION WRITE(108.200)
PC=PC+CABS(SC(IS)) **2
PCAN=100
                                                                             SMAX
                                                                           WRITE(108.400)
WRITE(108.500)
WRITE(108.500)
WRITE(108.200)
                                                  WRITE(108.200)
                                                           WPITE (108,300)
                                                                    WRITE (108.200)
                                                                                                             RADG (1) #PCAN
                        RARG(1) *PCAN
                                                                                                                                              RETURN
 0
                                                                                                                                      U
                 44.
                                                                                                                                      60.
61.
62.
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Table 2-15. Functional Description of Modules Comprising BCRS

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· ·	0 0 0	MATMIN	į.	MAIN EXFERITIVE BEGRESSES IT CALL OTHER EXFERTIVE SUPPRORAMS
~	000	•	ı	MHICH TOGETHER PERFORM THE DIGITAL ARRAY PROCESSING USING BATCH
•	8			COVARIANCE RELAXATION.
ř	000	- 1		
	9	SETIS	•	EXECUTIVE SUBPROGRAM. IT IS DESIGNED TO READ FROM THE INPUT DA-
<u>.</u>				IA FILE BUNSING THE GENERAL INFO AND COLFUI SUBROCHINES
21				RM- REIRC. AND SKIPK IN ACCURDANCE TO PRESE! FORMAT. ALL DATA I
13				MADE AVAILABLE TO APPROPRIATE SUBROCIIMES THROUGH COMMON BLUCKS.
15.	.000 RY:	S	•	GENERAL SUBPROGRAM. (DEFINED IN SIGGEN.)
- 16.	000	ì		•
- 17,	8	RCIS	•	GENERAL SUBPROGRAM, (DEFINED IN SIGGEN.)
- 19	000			
19.	6	PRIS	•	GENERAL SUBPROGRAM. (DEFINED IN SIGGEN.)
- 20,	000			
- 21,	8	EXECIS	•	CUTIVE SUBPROGRAM. IT CALLS DEDICATED SURPROGRAMS
- 22,	ê			BCR SIMULATION AND
- 23	9			ONS TAKE PLACE IN THIS SUBPROGRAM.
- 24.	000			
- 25	8	0815		DEDICATED SUBPROGRAM. THIS SUBPROGRAM WILL COMPUTE THE RATCH CO-
- 26.	Ę			ANCE MATRIX OF THE AUXILIARY PORT SIGNALS
- 27,	9			THE CROSS CORRELATION VECTOR OF THE MAIN PORT SIGNAL AND AUXILI-
- 28.	9			ARY PORTS SIGNAL VECTORS (FORCING VECTOR).
· 29.	000			
30,	.00	SIMIS	•	
- 31,	9			
- 32.	ŝ			TOR USING THE COVARIANCE MATRIX AND FORCING VECTOR.
- 33,	9			
34.	60	NIS	•	
35.	9			MENT FOLLOWED BY AN INTEGER. REAL. OR COMPLEX SCALAR. OR BY REAL
36.	9			OR COMPLEX ARRAY PLACED INTO AN 80-COLUMN FIELD.
37.	60			
. 3A.	Š	SUPIS	•	DEDICATED SURPROGRAM. IT IS DESIGNED TO COMPUTE THE RELATIVE
30'	٠.			COMBINED POWER SUPPRESSION AT SPECIFIED BCR ITERATIONS.
• • • •	000			
- 41.	ě	ERIS	•	DEDICATED SUBPROGRAM. IT IS DESIGNED TO FORM AN ARRAY BY CONCA-

IT ALSO NORMALIZES THE DEDICATED SURPROGRAM. THIS SUBPROGRAM WILL USE THE FINAL VALUE OF THE ADAPTIVE WEIGHTS TO COMBINE THE MAIN AND AUXILIARY PORT SIGNALS. FROM THIS IT CALCULATES THE POWER SUPPRESSSION RATIO. (DEFINED IN SIGGEN.) TENATION OF THE ADAPTIVE WEIGHT VECTORS. ARRAY WHEN DIRECTED TO DO SO. SURPROGRAM. GENERAL . CMBSGNL:S RCNORM 1S 44.000 45.000 47.000 51.000 45.000 43.000 16.000 18.000 19.000 50.000 15 84 69 69 95 7

Table 2-16. JCL Program, JCLBCRS:BL

| JOB | 1269.DANIEL (8512) +7.BLDG90 |LIMIT (TIME.1) + (U0.2) + (C0.16) + (ACCOUNT) OVER BCRS18 OVER BCRS1L SKIPR: B. 1269 RCNORM: R. 1269 PWRSUPIR. 1269 WITER18.1269 CMBSGNL 18, 1269 BCRSIMIB. 1269 FORM18.1269 RWIRC18.1269 BCREXECIB, 1269 CANDBIR.1269 BCRSET18,1269 BCRMAIN:B.1269 RW18.1269 ILYNX RCRS18

2.3.2.3 Binary Modules

Each source module in the BCRS program has its corresponding binary version. As shown before, the general JCL program, JCL:B, (see Table 2-2) can be used to create any of these binary modules.

2.3.2.4 Composite Binary and Load Module

The creation of the executable load module for the BCRS program can be accomplished through the execution of the JCL program, JCLBCRS:BL, which is shown in Table 2-16. This program works in the same manner as the one described in paragraph 2.2.2.4. Here, all the member-programs of RADAR:LIB pertaining to BCRS are concatenated to form the composite binary module, BCRS:B. This new module then is linked with necessary system functions to form the executable program, BCRS:L.

2.3.3 Program Execution

The program BCRS:L can be executed upon assigning the proper input and output files. The input file for this case is BCRS:D, the one discussed in paragraph 2.3.1. If the output is planned to be used as input to a subsequent program, as in this case, it should be a file other than the normal line printer output.

One of the methods of file assignments and program execution is shown as the JCL:X in Table 2-9. This general program can be executed by entering the interactive command

!BATCH JCL:X 'NAME' = BCRS

When completed, there will be an output data file, BCRS:0, which will contain the results of the BCRS program run.

2.3.4 Output File - BCRS:0

The output data file, BCRS:0, is shown in Table 2-17. It was produced by executing BCRS:L with input data BCRS:D. Up to the port 0 signal list, BCRS:0 is identical to BCRS:D[†]. This is done to insure that the output is interpreted in the proper context and is also a way of passing BCR and system description data to the subsequent program. The result of the BCRS process output begins with the covariance matrix and the forcing vector if IWCB = 1. These are followed by the BCR simulation output. That begins with the initialization stage and continues with a listing of pertinent quantities of each subsequent iteration, two in the present case. A composite weight-vector listing that follows includes a normalized set of all weight-vector iterates.

Note that the sequence numbers preceding each entry is not a part of the output data but is a useful artifice for editing. However, as a consequence of this keying, BCR performance data has exceeded the page size and hence not shown. For this benchtest example, however, it will be crucial to have the sequence numbers, especially in explaining the formation of the BCRP:D input data file that follows.

Table 2-17. Output Data File of the BCR Simulation Program, BCRS:0 Benchtest Example (See Figure 2-2)

		ONISA	•					
		BATCH COVARIANCE RELAXATION						
PRINT OPT	TIONS	· · · · · · · · · · · · · · · · · · ·						i
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		SPECIFICATION OF SYSTEM PARAMETERS	TERS					
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53 -	- 4847	LOWPASS/BANDPASS OPTION	~ →
54 -		0 1 LOWPASS	
55 -		1 1 BANDPASS	
S6 -			
57 -	HANNEL	PARAMETERS	
58 -	*****		
59 -	NCHNLS	NUMBER OF CHANNELS PER PORT	20
90	180	CHANNEL SELECTOR ARRAY	0
- 19			
- 29			
63	CHANNEL 11		
• • •	N	AMPLITUDE OF NOISE SOURCE	1.00000
65	- 0XI		~
99	1 Z	SAR	~
- 19	Œ	IN SAMPLES	10000
68	1	OF INCIDENCE	1 45.00000
69	- 1300	CHANNEL DELAY IN SAMPLE-TIME UNITS	00000
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7	CHANNEL 21		
72 -	· V		1.00000
73	- 0XI		
- 12	ī	FIRST-TIME-ON SAMPLE NUMBER	
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76 -	I	ANGLES OF INCIDENCE	10.0000
11 -	- Taus	CHANNEL DELAY IN SAMPLE-TIME UNITS	10000
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5	BUOFF		00000
92 -	PDEL	0	00000•
93	}		
1	PORT 11		
95	MEL	- NUMBER OF ANTENNA ELEMENTS	-
96	- 1001	F THE FI	
- 26	BWFCTR -	- BANDWIOTH TOLERANCE FACTOR	1 1.00000
96		- BANDWIDTH OFFSET FACTOR	00000
5	POEL	- FRACTION OF MAXIMUM APERTURE DELAY	00000
100			
101	PORT 21	-	
102 -	138	- NUMBER OF ANTENNA ELEMENTS	
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113 -	POEL	- FRACTION OF MAXIMUM APERTURE DELAY	90000
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127		RECEIVED BASFBAND PORT ST	SIGNAL

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	128 -		ON	ORMAL IZATION	CONST	•	359902E+00		
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2 - 51195	-	.8911	9380	.8658	.9180	.5138	.7168	.0119	.3704
3 68070 18359 18504 05666 01952 18359 18504 01966 01963 01952 28359 1806 01963 23173 2826 2836 2836 2836 2836 2836 2836 2836 2836 2836 2836 2836 2866 <td< td=""><td>32 -</td><td>5179</td><td>0706</td><td>6995</td><td>4886</td><td>3340</td><td>3715</td><td>.7232</td><td>5652</td></td<>	32 -	5179	0706	6995	4886	3340	3715	.7232	5652
	M	.4807	.2375	.2835	1350	•056	1033	1750	9200
50005511476 .45160 .317952216305661531582200 6057811059622783 .22798 .1304603938 .22899 665912105962278322798 .15059 .46555 .49784 .37381 746477 .5519024890 .000952233222121 .1788322994 114506082804817423735223222121 .178832094 114506082804817423735223222121178932094 114506082804817423735223222121178932094 2256041254916455451348 .0459216574 .453973269 22604126493441501659216574453973469 210177266653466163761637716377163761649 210170411710645923581167616876089782489 22017141171064592569116379256961549 220183304019326256922729725939256561549 2201833140112025691176117611899 220183314013345164961649117611899 220193314017612664818391184928919089182892 3204943530435301184928962896289192891908919 2207140744548518492891018492891918491891 32049418921892189492891918911899 .	•	.0635	.1128	.2757	.25A3	.11.	0386	0795	2761
	'n	.0005	.1147	4516	3179	.250	.0566	.5315	.2300
760312	٠	1071	.0553	2968	0398	.221	.1324	.3217	228
0.05924 0.0596 0.22783 0.27798 0.15059 0.04556 0.49784 0.3738 0.05924 0.00077 0.00097 0.00095 0.2232 0.27121 0.17893 0.22459 0.00092 0	_	.3758	9600	.038B	0260	232	1804	.0393	2649
0	- 96	.6031	.1659	.2278	.2779	150	0455	4978	3738
1	- 65	0592	2000	.6701	.2671	.517	.1755	4151	4249
1.506	0	4647	5519	.2489	6000	.223	.2212	.1788	.209
2 - 24552	-	.1450	.0828	.481	.3335	.158	.23R6	0301	1223
4 56041 25491 64554 51348 04592 16574 45397 3368 4 15139 26463 54150 23293 165092 05293 03784 7 0777 26464 13466 10226 16876 08787 16779 20464 13438 26581 57297 16876 08787 17532 33446 1771 66224 57297 59389 25668 38487 17867 17877 45485 68224 61877 59389 25668 38487 17867 17877 45689 25668 38487 17877 178	2	.2455	0715	071	1098	790	4889	4213	4266
515339		.5604	.2549	645	5134	045	1657	4539	3368
570177	•	.1533	.2046	.601	4315	.232	1509	.0529	0378
7034198	- 51	7017	2696	665	3540	765	5036	3314	1120
70734410328 .46115 .36154 .51851 .34287 .17532 .3344 801579 .2044 .13438 .29128 .17331 .08766 .00878 .1249 9217013971317867 .23581 .68668 .85575 .08121 .25858 140744 .45485 .68224 .67182 .68668 .85575 .08121 .25858 230583 .30440 .19326 .26502 .49589 .22002 .67978 .4159 3310489 .53454 .35300 .05499 .22966 .01299 .07721 .25858 453392 .59253 .00845 .13345 .27763 .77421 .19309 .00848 567038 .15448 .09812 .07694 .11141 .19319 .00818 609846 .05803 .32363 .11191 .70204 .51644 .42421 .1595 609846 .05803 .32363 .11191 .70204 .51644 .42421 .1595 735976 .29671 .25861 .31601 .34769 .005135 .29570 .17155 9229163 .15488 .209462 .15594 .23361 .31393 .02263 .05263 .0523 108273 .17843 .09462 .15594 .23530 .08516 .11599 .0995 229163 .16492 .11299 .08524 .11257 .27772 .18666 .4465 108273 .17843 .09462 .15594 .23330 .08516 .11599 .0995 2880547 .00000 .00073 .80534 .33321 .58546 .58734 .33458 .33458	9	3419	1607	.228	0450	.102	1687	0897	2486
801579 .20464 .13438 .291281733108766 .00878 .12499		0734	.1032	461	3615	518	3428	1753	3344
921701	0	.0157	2046	134	2912	.173	.0876	0087	1249
171101390131786731976 .16877 .4500315970 .1544 140744 .45485 .68224 .67182 .68668 .8557568121 .2585 23048053454 .19326 .2650226986 .012996079702184 253392 .5925308945 .133455634537763774213607 3670381584809812 .0761907994 .11141193090009 4670381584809812 .0761907994 .11141193090009 5670381584809812 .0761907994 .11141193090009 6098660580332363111917020451349 .20270 .17159 722916315834 .20011 .26848 .21790 .33672 .14524 .0903 922916315834 .20011 .26848 .21790 .33672 .14524 .0903 108273 .17843 .09462 .155942343008516 .115990995 208273 .17843 .09462 .155942343008516 .115990995 208273 .17843 .09462 .155942343008516 .115990995 680547 .0000000073 .80509 .5875333441 .33558 .58899 980547 .0000000073 .80509 .5875333441 .33558 .58899		.2170	.4177	990	.2358	572	.5938	.2565	.3852
140744 .45485 .68224 .67182 .68668 .8557508121 .2585 230583 .30440 .19326 .265024958922002679784159 330489 .53364 .35300 .0549929986 .01299080970218 453392 .59254 .08945 .1334537763377613607 5670381544809812 .111917020451644424211595 609846 .0580332363111917020451644424211595 735976 .29671 .55861 .31601 .3476905135 .29570 .1715 929163 .1689840331401633326131393 .02263 .0523 929163 .1689840331401633326131393 .02263 .0523 929163 .11894 .20011 .26848 .21790 .33672 .14524 .0903 929163 .18643 .09462 .155942343008516 .115990995 229163 .17843 .09462 .155942343008516 .115990995 3 - 1	9	.7110	.3901	.178	.3197	168	1500	1597	1544
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453392 .5925308945 .133455634537763774213607 5670381584809812 .0761907994 .111411930900099 60984605803323631119170204516444242115955 735976 .29671 .55861 .31601 .3476905135 .29570 .17155 802046 .1689840331401633326131393 .02263 .05233 92916315834 .20011 .26848 .21790 .33672 .14524 .09033 108273 .17843 .09462 .155942363008516 .115990995 229163 .17843 .09462 .155942363008516 .115990995 3 - 100273 .17843 .09462 .155942363008516 .115990995 580547 .0000000073 .80509 .5875333441 .33558 .58899 980547 .0000000073 .80534 .5332158546 .587343345	53 -	.3048	.5385	3530	0549	.299	0129	.0809	.0218
567038	. 43	5339	5925	.0894	1334	.563	.3776	.1742	.3607
6098460580332363111917020451644424211595 73597629671 .55861 .31601 .347690513529570 .1715 802046 .1689840331401633326131393 .02263 .0523 9291631583420011268482179033672 .145240903 0129431409211299085241125727772 .188664465 11082731784309462155942363008516115990995 2082731784309462155942363008516115990995 3 - 1 4082731784309462155942363008516115990995 5805470000000073805095875333441335585889 90007380534000003332158546587343345	55	.6703	.1584·	.0981	0761	.0799	11114	1930	6000
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802046 .1689840331401633326131393 .02263 .0523 92916315834 .20011 .26848 .21790 .33672 .14524 .0903 012943 .1409211299 .08524 .11257 .27772 .18866 .4465 108273 .17843 .09462 .155942363008516 .115990995 208273 .17843 .09462 .155942363008516 .115990995 3 - 1 400673 .0000000073 .80509 .5875333441 .33558 .5889 00007380546 .000003332158546 .587343345	- 19	3597	967	5586	3160	3476	.0513	2957	1715
92916315834 .20011 .26848 .21790 .33672 .14524 .0903 012943 .1409211299 .08524 .11257 .27772 .18866 .4465 108273 .17843 .09462 .155942363008516 .115990995 208773 .17843 .09462 .155942363008516 .115990995 3 - 1 4	83	.020	1649	4033	* 4016	.3326	3139	9220	0523
012943 .1409211299 .08524 .11257 .27772 .18866 .4465 108273 .17843 .09462 .155942363008516 .115990995 208273 .17843 .09462 .155942363008516 .115990995 3 - 1 4 5 COVARIANCE MATRIX C A 6 80547 .0000000073 .40509 .5875333441 .33558 .5889 0 80547 .0000000073 .40509 .5875333441 .33558 .5889	20	.2916	.1583	2001	684	2179	3367	1452	6060
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2	- 15	0827	784	9460	2 29	2363	0851	159	9660
3 - 1 4	25		-	**********	Ì	ŧ	Ì		
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COVARIANCE MATRIX C NORMALIZATION CONSTANT 1 .152546E+02 880547 .0000000073 .80509 .5875333441 .33558 .5889	! !	Ì			!				• • • • • • • • • • • • • • • • • • • •
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880547 .0000000073 .80509 .5875333441 .33558 .5889 00007380509 .80534 .000003332158546 .587343345	 ? ?		Ž	ATTO) VINIV	52546F+0		
980547 .0000000073 .80509 .5875333441 .33558 .5889 00007380509 .80534 .000003332158546 .587343345	60) - [•			
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	2	• 0001	.8050	8053	000	.3332	.5854	5873	• 3345

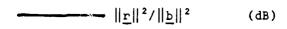
				,	ACCE .		08666		.01417	.01417		.00000.					.44687
				. 446.6	2000	00000	99954		.01176	.01176		00000					.44410
*60000	-1.00000	BCR SIMULATION		.58753	-, 33321	1.00000	-00052		*6866*	.99894	40800	.00000					3.08305
99980 4 . 99980 01	6 .01417	OF BCR SI		.80509	00000	.58546	.33458		A5123	85123	85123	• 00000					-2,55255
00000 99954 .720710E.01	.01176	PERFORMANCE SUMMARY OF		00073	.A0534	33321	.58734		12721	12721	12721	.00000					85879 -
1.00000 .00052 VECTOR B	*6966*	PERFORMANCE		00000.	80509	.33441	58896		12855	-,12855	-,12855						85971
.58546 .33458 FORCING CONSTANT	85123			.80547	00073	58753	.33558			.85241 -			.00000			•	2.55656 10.74911
~33321 •58734 HALIZATION				-		-	-		• •		-		·-			••	1 2.5
, ē	12855		CONDITIONS														
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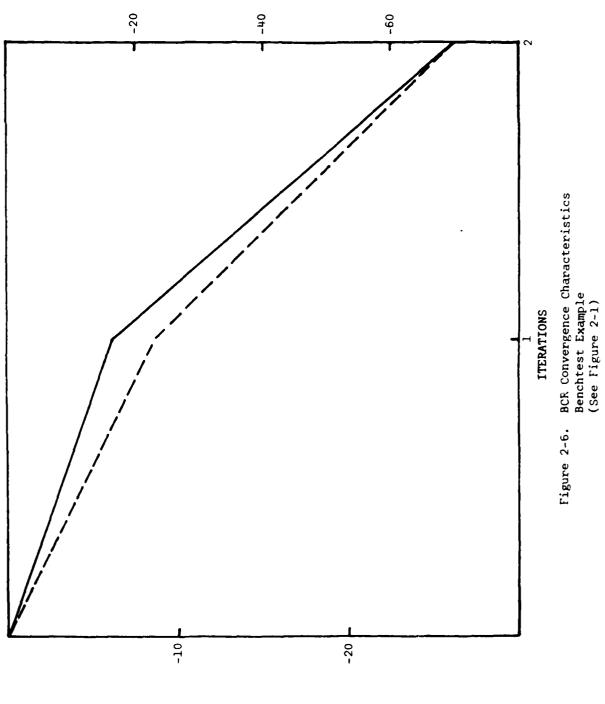
				GNAL ,230300E-01	PORT SI	D BASEBAND CONSTANT	RECEIVED HALIZATION	NORMA	
		# 0 0 1 1 1 1	1 0 0 0 0		PORT	COMBINED PORT	1 1 6 9 9 1 1	1 1 1	
		.00000	.00000	.00000 .01013 .76653	900	. 00000 . 73304 . 99306	• • • • •	.00000 .11070 75511	0.76
			LION	TED BCR ITERATION	INDICATED 1 .177	ANI	351	ADAPTIVE NORMA	
				ARRAY	•	WE I GH	COMPOSITE		
.00003	0000+	00017	.00040	*0000	00002		- 52		POC (DR)
						65309	69-		ROBD8
• 00003	00003	00017	.00040	• 00005	-00005	. 00040	•• ••		R R R R R R R
,)))			• ••		WNORM
26400	28835	-, 37553	77256	28686	28405				ALPHA
05894	05959	.00017	01116	.06812	.06767	.01075	•• •		80
					ı	N			ITER
						.54392	6 0		P0C (04)
7001	14144	F 91 CO.	04414	.14803	14696	.02325	10 es		BETA
						.28455 6.33525	•		RVORM ROBOB
アンクー・ト							1 - 16		
1 2060	13210	.00020	02434	.15099	.14995	.60450			ENORE R

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And the second s

.19239	.12023	.09309	4 N I I	1 1	237	2773 .0088 5240 .0735 : 25.23703	07 -,22773 ,0088 71 -,25240 ,0735 1 : 25,23703
0028	0599	0660	6440		0088	22773 .0088	410722773 .0088
	800	35.0	054	» ac	508	11334 • 6007	764611334 .cusy 4002172122505
583	248	162	8	•	6990	4875 .0469	5598 .24875 .0469
769	1060	1566	610	.	1155	10831 ,1155	04263 .10831 .1155
0703	4671	0260	4452	_	1423	602831423	25167 .602831423
0808	243	1215	27066	- Œ	353	.01804 .3353	01842 01804 3353
70	4206	136/	3192	M P	3214	29779 .3214 7736 04507	431129779 .3214
1195	017	624	38	se i	1299	2080 1249	1839 .020801249
1409	752	2056	275	Ç.	920	81734026	8153 .18173 4026
948	4300	1594	0040	•	0313	36406 .0313	109636406 .0313
13	3399	222	1247) (F)	351	8605 .1351	6096 .18605 .1351
1134	***	3070	763	0 u	282.	56413 .282	USIS6 ••66413 •282
824	0835	325	476	_	007	3386 .007	134033386 .007
2648	649	152	065	60	.076	7501076	344357501076
0326	6457	3937	3191	7	121	16356 121	639016356121
40361	74138	273	5.7	* C	100	1959 1950.	9700853 -0501 85 -610532926
49	1504	024	3184	_	0990	3521 .0660	2997 .13521 .0660
3749	6069	2623	1206	•	1534	33631 ,1534	3956233631 .1534
1070	1272	299	1548	•	1959	2495 1959	03208 .524951959
2088	5967	0442	.2697	_	849	76398 1849	08672 .763981849
0	4119	386	.1912		1612	54976 .1612	2318254976 .1612
575	2692	4422	7763	٠,	0298	08912 - 0298	9820 - 08912 - 0298
0554	6123	245	3979	_	1538	23095 .1538	0351023095 .1538
167	920	2692	8896	S	0162	10647 .0162	2750610647 .0162
181	629	3792	469	O	.0496	8928 0496	7935489280496
.2505	888	776	685	•	124	07463124	0A13 .07463124
			7	D	-		11. 00061. +3610





 $b^{C}(\overline{m})\backslash b^{0} \qquad (B)$

Valuable insight into the BCR process may be gained by careful examination of the printed output. For example, the relative combined power suppression, 10 $\log_{10}(P_{(w)}/P_{0})$, and the relative gradient metric, 10 $\log_{10}(\|r\|^2/\|b\|^2)$, pertain to the nulling performance and convergence, respectively. In the output listing of Table 2-17, these quantities are -POC and ROBDB given in dB. Figure 2-6 summarizes the behavior of these parameters as a function of iteration for the benchtest example under consideration.

Whereas POC is computed directly from BCR variables at each iteration, it is also computed directly, at the end of the process, using the explicit combined signal listed next in BCRS:0. This value of POC which may differ from its equivalent indirect computation is listed last.

2.4 BCR Performance and Plotting Program - BCRP

The purpose of the BCRP program is to analyze the performance of the BCR process and produce graphical output that characterizes this performance. As such, it uses the data produced by the BCRS program.

2.4.1 Input Data File - BCRP:D

The input data file, BCRP:D, for the BCR performance and plotting program, BCRP, is shown in Table 2-18. It happens to be a subset of BCRS:0 except for one character; namely, "X", the unspecified number of actual iterations in the header data file, BCRS:D0.

The BCRP program requires all BCRS:0 information except any C and b output or the BCR performance summary. To create BCRP:D from BCRS:0, the first change on BCRS:0 is the entry of the actual number of iterations (2 in our case) over and right-justified to the letter "X". Subsequently, all C and b and BCR performance data ranging from lines 165 ghrough 239 is deleted, which is obvious by noting the missing range of numbers in Table 2-18.

2.4.2 Program Structure

The BCRP program was designed with the same methods as the previous two major programs. It has a similar modular-linear structure with the data input restricted to one executive program branch. The "library" approach is used by referencing subprograms, many of which were already introduced in earlier programs. Details of the program structure are given in the following paragraphs.

2.4.2.1 Tree Diagram

The structure and modular order of execution of the BCRP program are clearly demonstrated by the tree diagram of Figure 2-7. The data input is alone in the BCRPSET branch, again using the utility subprograms RW, RWIRC, and SKIPR. The main program, BCRPMAIN, calls a series of dedicated subprograms. CMPCHNL is called to generate composite baseband channel amplitude responses. The resulting quantities are printed and held for plotting. Next, FIELD is

[†] See equation (3-86) in Project Memorandum 8512-03.

Table 2-18. Input Data File of the 3.R Plotting Program, BCRP:D Benchtest Example (See Figure 2-2)

ADAPTIVE ARRAY PROCESSING USING COVARIANCE RELAXATION	# 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	SIGNAL SAMPLES : 256 NAL WEIGHTS : 20 REAT : 1 1 1 1 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1	IONS 1 2 SYSTEM PARAMETERS	WEIGHTING 1 0 AND PHASE 1 0 SPONSE 1 0 ND PHASE 1 0
DIGITAL	OPTIONAL OUTPUT OF SO OPTIONAL OUTPUT OF SI OPTIONAL OUTPUT OF C	MAXIMUM NUMBER OF SIGNAL SAM SIZE OF BAND DIAGONAL MAXIMUM NUMBER OF WEIGHTS WEIGHT SELECTOR ARRAY MAXIMUM NUMBER OF ITERATIONS	CTUAL NUMBER OF I SPECIFICATI	MAIN ANTENNA ARRAY RECEIVER AMPLITUDE RECEIVER IMPULSE RE CHANNEL IMPULSE RES
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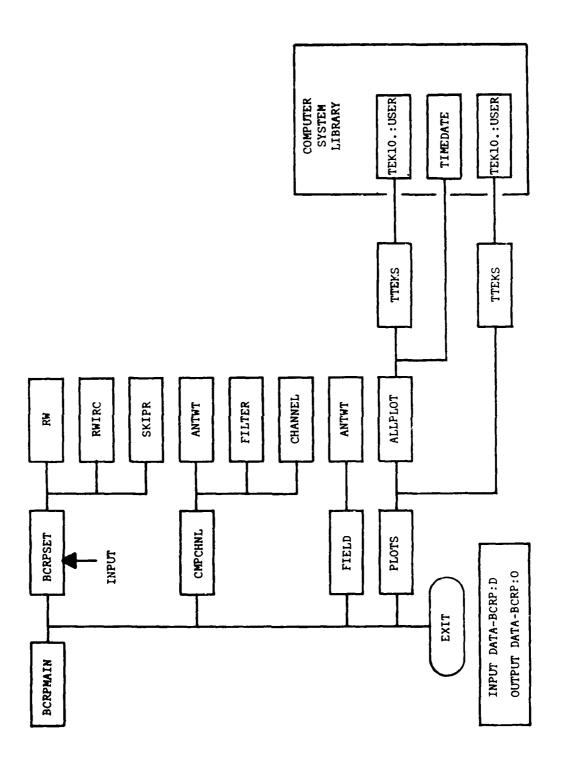


Figure 2-7. Tree Diagram of the BCR Plotting Program, BCRP

called to compute the electric field in the angular neighborhoods of the noise sources. The amplitudes of the fields over a 0.25° window are printed and held for plotting. The last branch of the structure is the plotting branch, PLOTS. It directs an auxiliary plotting program to output on a CRT several pictures containing the relevant plots in a desired format. The module called TEK.:USER is a collection of TEKTRONIX functions and subroutines which are part of the system library; therefore they are not transportable with BCRP. Also, it makes BCRP:L dependent on the availability of certain TEKTRONIX terminals.

All the data which are to be plotted are available prior to calling the PLOTS branch. Since PLOTS is the only branch which needs TEK.:USER, it is possible to remove or replace the PLOTS branch. Removal is accomplished by simply eliminating the PLOTS branch and the call to it. Replacement is done by substituting subprograms which interface with BCRP as PLOTS does, and uses local system-supported plotting software and hardware.

2.4.2.2 Source Modules

The source program list of BCRP is given in Table 2-19. To each subprogram in this list there is a corresponding named module in the BCRP tree diagram. Since all of these subprograms are members of the RADAR:LIB, those with the familiar names, such as RW, RWIRC, etc., refer to the specific member-program already described for earlier programs. A functional description of the newly introduced source programs is given in Table 2-20.

2.4.2.3 Binary Modules

Each source module in the BCRP program has its corresponding binary version. As shown before, the general JCL program, JCL:B, (see Table 2-2) can be used to create any of these binary modules.

2.4.2.4 Composite Binary and Load Modules

The creation of the executable load module for the BCRP program can be accomplished through the execution of the JCL program, JCLBCRP:BL, which is shown in Table 2-21. This program works in the same manner as the one described in paragraph 2.1.2.4. Here, all the member-programs of RADAR:LIB pertaining to BCRP are concatenated to form the composite binary module, BCRP:B. This new module is then linked with the TEK.:USER library and other necessary system supplied functions to form the executable load module, BCRP:L.

2.4.3 Program Execution

The program BCRP:L can be executed after assigning the proper input and output files. The input file for this case is BCRP:D, discussed in paragraph 2.4.1. The printed output can go to a similar file, or to a line printer. This program was designed to be executed in an interactive mode. Using a TEKTRONIX terminal, it is necessary to assign the input and output files. One of the ways this can be done is by entering the two successive device assignments

!SET F:105/BCRP:D !SET F:108/BCRP:0

FORTRAN Listing of Source Modules Comprising the BCR Performance and Plotting Program, BCRP:S Table 2-19.

	C BCH GRAPHI C BCH GRAPHI C BCH GRAPHI C BATC C BATC C BATC C BREEZESSESSESSESSESSESSESSESSESSESSESSESSE	BCH GRAPHICAL OUTPUT PROGRAM : BCRP:S BOTCH COVARIANCE RELAXATION PROGRAM : BCRPWAIN:S ORIGINAL : JULY 23, 1980 REVISION : FEBRUARY 3, 1981 PREPARED BY : S, M, DANIEL & I, KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS DIV. TEMPE, ARIZONA 85282 CALL BCRPSET CALL CMPCHNL
20.	CALL FIELD	
21.	CALL PLOTS	
22.	CALL EXIT	
23.	END	

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SELECTED WEIGHTS ARE NOT COMPATIBLE WITH DESIGNATED
                           COMMON /BCHP4/ S0(256),W(20),WIT(21,20),SC(256),AS0(256),ASC(256)
                                                                                                                                                                                                                                                                                                                              COMMON /BCRP3/ BWFCTR(21), BWOFF(21), PTAU(21), DO, NEL(21), LOC1(21)
                                                                                                                                                                                                                                                                                     COMMON /BCRP1/ POL(6), FBIF, FBRF, KADRNG, RADIN, DRAD, NPOL, LPRP, NF
                                                                                                                                                                                         MOTOROLA GOVERNMENT ELECTRONICS DIV.
                                                                                                                                                                                                                                                                                                  COMMON /BCRP2/ AH0(64.20), AHC(64.20), TH(20), CTAU(20), ISC(20)
                                                                                                                                                             S. M. DANIEL & I. KERTESZ
RADAR SYSTEMS ANALYSIS GROUP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               READ IN WEIGHT SELECTOR ARRAY OVER DESIGNATED PORTS
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          MAIN-PORT AND COMBINED-PORT SIGNALS
                                    SPECIFICATION OF SYSTEM PARAMETERS
                                                                                                                                                                                                     TEMPE, AHIZONA 85282
                                                                                                                       23, 1980
                                                                                                                                   FEBRUARY 13. 1981
                                                                                                                                                                                                                                                                                                                                                                      -,X(256),AL(1001),ISW(20),NS,NWX,ITER,ITER1
                                                                              ADAPTIVE-WEIGHT ITERATES
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               READ (105:100) AR14.(ISW(IW).IW=NW1.NW2)
                                                                                                         BCHPSET:S
                                                                                                                                                                                                                                                                                                                                                                                                                                                                       DATA PI/3.14159265/
COMPLEX POL.50.W.WIT.SC.COUM
                                                                                                                                                                                                                                  DATA FILE BCHPID
                                                                                                                                                                                                                                                                                                                                                                                    DIMENSION AR14(14) + AR12(12)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               CALL RWIRC (COUM.RDUM.NWX.0)
                                                                                                                                                                                                                                                                                                                                            -. 1SP (20) . 10P (21) .NPM1
                                                                                                                                                                 8
                                                                                                                                                                                                                                                                                                                                                                                                 FORMAT (1444.4X.1012)
          SUBROUTINE BCRPSET
                                                                                                                                                                                                                                                                                                                                                                                                               FORMAT (1244.E13.6)
                                                                                                                                                               PHEPARED
                                                                                                                                     REVISION
                                                                                                                        ORIGINAL
                                                                                                                                                                                                                                                                                                                -. IDC (20) .NCHNLS
                                                                                                          PROGRAM
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                                                                                                                                                                                                                                                                                                                                                                                                                                         FORMAT ( ....
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   CALL RW (20)
                                                                                                                                                                                                                                                                                                                                                                                                                                                       -PORTS
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    NW2=10
                                                                                                                                                                                                                                 INPUT
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2000 P

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READ IN CHANNEL SELECTOR ARRAY AND ASSOCIATED CHANNEL DESCRIPTIONS
                                                                                                                                                                                                                                                                          WRITE(108-100) ARI4+(ISW(IM)+IMENM1+NW2)
                                                                                                                                                                                                                                                                                                                                                   READ (105,100) AR14, (ISC(IC), IC#NC1, NC2)
                                                                                                                                                                                                                                                                                                                                                             WRITE(108,100) ARI4, (ISC(IC), ICENCI, NC2)
                                                                                                                                                      RWIRC (POL (IP) , ROUM, IDUM, 2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      CALL RWIRC (CDUM, TH(IIC), IDUM, 1)
                                                                                                                                                                                            RWIRC (COUM, RADRNG, IOUM, 1)
                                                                                                                                                                                                                                                                                                             CALL RWIRC (CDUM. RDUM. NCHNLS.0)
                                                                                                                                                                                                         RWIRC (CDUM+RADIN+1DUM+1)
                                                                                                                                                                    RWIRC (COUM.FBIF. 10UM.1)
                                                                                                                                                                                RWINC (CDUM.FBRF. IDUM.1)
                                                                                                                                                                                                                                                                                                                                                                                                                  NC2=NCHNLS
                                                                                         CALL RWINC(CDUM,RDUM,ITER,0)
ITERI=ITER+1
                                                                                                                              RWIRC (CDUM, RDUM, NPOL, 0)
                                                                                                                                                                                                                                               CALL RWIRC (CDUM. RDUM. LPBP.0)
                                                                                                                                                                                                                                                                                                                                                                                                     IF (NC1.6T.NCHNLS) GOTO 4000
IF (NC2.6T.NCHNLS) NC2=NCHNLS
                                                                                                                                                                                                                    RWIRC (COUM, ROUM, NF . 0)
                                     IF (NW1.GT.NWX) GOTO 2000
                                                                                                                                                                                                                                                                                                                                                                                                                                                                    IF (ISC (IC) . Eu. 0) 6010 20
                                                  IF (NEZ. GT.NEX) NEZENEX
                                                                                                                                                                                                                                                                                                                                                                                                                                                       DO 20 IC=1.NCHNLS
                                                                                                                                          DO 10 IP=1.NPUL
                                                                                                                                                                                                                                  DRAD#RADRNG/NF
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         10C(11C)=1C
                                                                                                                   CALL RW(18)
             NELENET +10
                         NAZMNES+10
                                                                                                                                                                                                                                                                                                                                                                             NC1=NC1+10
                                                                            CALL FW(2)
                                                                                                                                                                                                                                                                                                                                                                                         NC2=NC2+10
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  CALL RW(1)
                                                                                                                                                                                                                                                             CALL RW(S)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   CALL RW(6)
                                                               60TO 1000
                                                                                                                                                                                                                                                                                                                                                                                                                              60TO 3000
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                                                                                                                                                                                                                       CALL
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SELECTOR ARMAY AND ASSOCIATED PORT DESCRIPTIONS
                                                 AUGMENT PORT SELECTOR ARRAY VIA WEIGHT SELECTOR ARRAY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  READ IN. DENURMALIZE AND COMPUTE AMPLITUDE OF
                                                                                                                                                          READ (105,100) ARI4, (ISP(IP), IPENPIENP2)
                                                                                                                                                                       WRITE(108.100) ARI4.(ISP(IP).IP=NPI.NP2)
                                                                                                                                                                                                                                                                                                                                                                                                                                         RWIRC (CDUM, BWFCTR (IIP) , IDUM.1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                      RWIRC (CDUM, BWOFF (IIP) . IDUM.1)
                                                                                                                                                                                                                                                                                                                                                                                                                            RWIRC(CDUM, RDUM, LOC1 (IIP) .0)
                                                                                                                                                                                                                                                                            IF (ISP (IP) .NE. ISW (IP)) GOTO 9999
                                                                                                                                                                                                                                                                                                                                                                                                              CALL RWIRC (COUM. ROUM. NEL (IIP) .0)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                  CALL RWIRC(CDUM, PUEL, IDUM, 1)
IF (IP, EQ, 1) PTAUX=PI*DO*NEL(1)
                                                                                                     CALL RWIRC (COUM. ROUM. NPORTS.0)
                                                                            CALL RWIRC (CDUM.DO.IDUM.1)
                                                                                          RWIRC (CDUM.RDUM.NS.0)
                                                                                                                                                                                                            IF(NP1.GT.NPM1) GUTO 6000
IF(NP2.GT.NPM1) NP2=NPM1
                                                                                                                                                                                                                                                                                                                                                          IF (ISP (IP1) . Eq. 0) 6010 40
                                                                                                                                                                                                                                                                 SP(IP) #ISP(IP) #ISM(IP)
                                                                                                                                                                                                                                                                                                                   00 40 IP=1,NPORTS
IF(IP-EQ-1) GOTO 7000
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           PTAU(IIP) *PDEL *PTAUX
                                                                                                                                                                                                                                                    DO 30 IP=1,NPM1
                                                                                                                   NPM]=NPORTS-1
                                                                   READ IN PORT
                                                                                                                                                                                                                                                                                                                                                                                                  [4]=(d][)d0]
                                                                                                                                                                                                NP2=NP2+10
NCHNLS=11C
              CALL RW(3)
                                                                                                                                                                                     NP 1 = NP 1 + 10
                                                                                                                                                                                                                                                                                                                                                                           CALL RW(2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        NPM] = 1 1P-1
                                                                                                                                                                                                                                                                                            CALL RW(2)
                                                                                                                                                                                                                                       60TO 5000
                                                                                                                                                                                                                                                                                                                                                                                     [IP=IIP+]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    [DP(1) *0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          CONTINUE
                                                                                                                                                                                                                                                                                                                                                PleiP-1
                                                                                                                                             NP2=10
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                                                                                            CALL
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READ IN AND DENORMALIZE ADAPTIVE WE GHT ITERATES
                                                                                                                                                                                                                                                                    READ IN. DENÓRMALIZE AND COMPUTE AMPLITUDE OF SC
                                                                                                                    READ (105,300) (WIT(IT.IP), IP=1, NPM1) WRITE(108,300) (WIT(IT.IP), IP=1, NPM1)
                                         READ (105+300) (S0(IS)+IS=1+NS)
                                                                                                                                                                                                                                                                                                                         CALL RW(1)
READ (105-300) (SC(IS),IS=1,NS)
                                                  WRITE(108,300) (S0(1S), 15=1,NS)
                                                                                                                                                                                                                                                                                                                                             WRITE(108,300) (SC(IS), IS=1,NS)
                                                                                                                                                                                                                          WIT(II.IP) =WIT(II.IP) +WITSCL
                                                                                                                                       READ (105.200) AR12.WITSCL
                                                                                                                                                 WRITE(108.200) AR12.WITSCL
         READ (105.200) AR12.50SCL
                    WRITE(108.200) AH12.505CL
                                                                                                                                                                                                                                                                                                   READ (105,200) AR12,SCSCL
WRITE(108,200) AR12,SCSCL
                                                                                   AS0 (15) =CABS (50 (15))
                                                                                                                                                                                                                                                                                                                                                                            ASC (1S) #CABS (SC (1S))
                                                            50 (15) = 50 (15) + 50 SCL
                                                                                                                                                                                                                                               M(IP) =WIT(ITERI, IP)
                                                                                                                                                                                                                                                                                                                                                                 SC(1S) #SC(1S) #SCSCL
                                                                                                                                                                                                     DO 70 IT=1,1TEH1
                                                                                                                                                                      00 60 IT=1.ITEM1
                                                                                                                                                                                                               DO 70 IPal.NPMI
                                                                                                                                                                                                                                     DO 80 IPELINPMI
                                                                                                                                                                                                                                                                                                                                                                                                                     WRITE (108.999)
                                                                                                                                                                                                                                                                                                                                                       SN+1#51 06 00
                               CALL RW(1)
CALL RW(7)
                                                                                                                             CALL RW(6)
                                                                                                                                                            CALL RW(1)
                                                                                                                                                                                                                                                                                         CALL RW(7)
                                                                                                                                                                                                                                                                                                                                                                                       CALL RW(3)
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ې د ډ					RADAK STSIEMS ANALTSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS DIV. TEMPE, ANIZONA RESRO	RONICS DIV.
• • • • •	TUPNI	N I INDUIT		•	NUMBER OF CINES TO BE READ AND WRITTEN	D AND WRITTE
"	***		***	11 90 94 96		61 14 16 10 11 11 11 11 11
	DIMENS	DIMENSION AR20(20)	(50)			
100	FORMAT	FORMAT (20A4)				
	DO 10 [#1.N	Z • 1 = 1				
	READ (105,100)	AR20			
10	WRITE (WRITE(108.100) AR20	AR20			
ı	RETURN					
	END					

۱.	
.	SUBROUTINE RAIRC (CX.RX.IX.IND)
	HEADING AND WHITING AN BO-CHARACTER LINE
٠ ن ن	CONSTING OF A SALCHARACTER COMMENT
	OVA
	A COMPLEX. REAL OR INTEGEM SCALAR VARIABLE VALUE
.00	PROGRAM : RWINC:S
	REVISION : AUGUST 13. 1980
	SUCCESSION OF MAINTER A TANGE OF THE MENTERS
	RADAR SYSTEMS ANALYS
	MOTOROLA GOVERNMENT ELECTRONICS DIV.
• • • • • • • • • • • • • • • • • • • •	**************************************
	IND
20. C	O I HEAD & WRITE
	HEAD & WRITE
22. C	2 : MEAD & WMITE COMPLEX
23. 24.	OUTPUT : CX - COMPLEX SCALAR EXCLUSIVE OF RX & IX
	RX - REAL SCALAR EXCLUSIVE OF CX & IX
26. C	IX - INTEGER SCALAR EXCLUSIVE OF CX 6 RX
29.	DIMENSION ARIA (14)
30. 100	
31. 200	FORMAT(1444+F12.5)
	FORMA
33.	ONI + (2+1)
•	A LANGUAGE CONTRACTOR OF THE C
35.	STITE (100*100) AT 1**IX
37. 1	READ (105,200) AR14,HX
38.	WRITE(108,200) AR14,RX
39.	
40. 2	_
• 1 •	WAITE (108-300) ARIA-CX
* 2•	A CAN
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	SUBROUTINE SKIPR(NU-NS)	BERNELLE STEEL SUBSCIENCE SUBSCIENCE STEEL	5	SUBROUTINE SKIPP (NU-NS)
Š	SKIP NS LINES ON UNIT NU.	ON UNIT NO	•	
	ă l	PROGRAM	••	
	& W	ORIGINAL REVISION		FEBRUARY 23. 1981 FEBRUARY 23. 1981
	ä	PREPARED BY	••	S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS DIV. TEMPE: ARIZONA 85282
i	INPUT :	N N N	•	NUMBER OF UNIT OR DEVICE NUMBER OF LINES TO SKIP
	OUTPUT :		•	NONE
	ENTRY POINTS SUBPOUTINES CALLED FORMAT(1X)	TS S CALLED	# #	ENTRY POINTS : SKIPR SUBROUTINES CALLED : NONE BERRELERERERERERERERERERERERERERERERERER
i	SKIP NS LI	SKIP NS LINES ON UNIT NU	į	
:	DO 10 I=1.NS READ(NU.100) RETURN END	000	İ	

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12.	U					RADAR SYSTEMS ANALYSIS GROUP
13.	U					MOTOROLA GOVERNMENT ELECTRONICS DIV.
14.	υ					TEMPE. AHIZONA 85282
15.	U					
16.	U	INPUT	•	SYSTEM		PARAMETERS IN COMMON
17.	Ü					
18.	U	001PUT	••	PHO	•	MAIN BASEBAND CHANNEL AMPLITUDE
19.	U					
20.	U			AHC	,	COMPOSITE BASEBAND CHANNEL AMPLITUDE
21.	U					RESPONSES
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•		NORMON			94. (0)	CONTROL VECTOR OF THE PROPERTY
25.		COMMON /BUXF2/	/BCK	2/ AMO	164.20	AHO (64.20) . AHC (64.20) . TH (20) . CTAU (20) . 15C (20)
26.		COMPON (SO) SUCHICE		INCS	1600	•IDC(20)•NCMNLS
• • •		NOTE OF		3/ DWT	17, 41,	+ DM OL 121 42 42 42 42 121 42 121
.07		THAN (17) 101 (07) 151 (-	10101	N 6 1 7 7 1	7 E	
29.		NOMMOD	18CK	205 /4	256) • 4	COMMON /8CRF4/ SO (256) + W (20) + W (11.20) + SC (256) + ASO (256) + ASC (256)
30.		- 14 (230		71 - (100)	1021#6	
31.			201	DIMENSION NO (04) +N (04) +NK (04)	1.000	
36.		_	7727			
33.	200		* - * * * * * * * * * * * * * * * * * *			
34.	306	_	(CCX +	PURMAT (ZZX+ BASEBAND		CHANNEL AMPLITUDE MESPUNSE
35.		•			1	
36.	400		(18X.	FORMAT (18X. MAIN-PORT BASEBAND	DRT BA	SEBAND CHANNEL AMPLITUDE RESPONSE
37.	1	•	5(1-1)	•/• (8F	10.51)	
38.	200		(18X.	COMPOS	ITE BA	FORMAT (18X++COMPOSITE BASEBAND CHANNEL AMPLITUDE RESPONSE +-/
39.	,	- 1 3 X + 4 E	2(1-1)	.18x+45('-'),/.(8F10.5))	10.5)	
	υL	3017000		DESTRUCTION OF THE PROPERTY OF		BOSTOLEGOUSTINESSESTEET OF THE SECTION SET SET SET SET SET SET SET SET SET SET
	, (22-1-23-7 242-2 FFF-1-2 - FFF-1-20 888888888888888888888888888888888888
, r	J	CALLAN	N. LAL		00111	1.8[.]
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•••			Program Original Revision	- 1 z	•• •• ••	ANTWT APKIL SÉPTE	ANTWIIS APKIL SÉPTEMBER 10	19.	1980 1980			
9			PREPARED	64 03	••	S. RAD MOT	S. M. DAR RADAR SY: MUTOROLA TEMPE, A	DANIEL SYSTEMS ILA GOVE ARIZON	S. M. DANIEL & I. KERTESZ Radar Systems analysis group Mutorola Government electron Tempe, ahizona 85282	KERTESZ SIS GROU ELECTRO	S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MUTOROLA GOVERNMENT ELECTRONICS DIV. TEMPE, ARIZONA 85282	• > 10
14. 15. 16.	INPUT	10	NEL LOC1			Z C	BER UN	ELE!	ENTS SER) OF	FIRS	NUMBER OF ELEMENTS IN LINEAR ARRAY LOCATION (NUMBER) OF FIRST ELEMENT	N + N
18.	00.1	OUTPUT :	AL			ARH	AY ELE	MENT	ARKAY ELEMENT WEIGHTING	9 1 1	71 84 91 91 91	OUTPUT : AL - ARMAY ELEMENT WEIGHTING
	DIM PIOR FOR	DIMENSION A FORMAT(1H1)	DIMENSION AL (1) FORMAT (1H1)		1 	† † †						
22. 200	(FORMAT(1X FORMAT(20	FORMAT(1X.79(***)) FORMAT(20X.*1AYLOR		VE I GH	TING	FOR	ZIAL	NTENN	A ARRA	WEIGHTING FOR MAIN ANTENNA ARRAY 7.20%	×
25. 400		MAT (8	FORMAT(8F10.5) DATA PI/3.1415965/	765/								
28.	COCLE	PI2=2+PI LOC=LOCI-1 CON2=0.5+(PI2=2+PI LOC=LOCI=1 CONZ=0.5+(NEL+I)									
32.		DO 10 I=1+NEL	1 • NEL	6								
2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0		11/41/4 11/4-60 176(10 176(10 176(10 176(10	AKGECONITY (COLTONS) AL (1) = 1 + 0.5 + CUS (AHG) IF (1W.EQ.0)	CAL C	(AHG) URN (AL(I).1=1.NEL)	1 • N	S					
41.	RET	RETURN										

			1	
EVALUATIO	N OF NOR	MALIZED AT DIS	# # # # # # # # # # # # # # # # # # #	EVALUATION OF NURMALIZED RECEIVER BASEBAND SAMPLED TRANSFER FUNCTION EVALUATION OF NURMALIZED RECEIVER BASEBAND SAMPLED TRANSFER FUNCTION AT DISCRETE RADIAN FREQUENCIES USER BASEBAND SAMPLED TRANSFER FUNCTION OF NURMALIZED BASEBAND SAMPLED TRANSFER FUNCTION AT DISCRETE RADIAN FREQUENCIES
ĭ	OWPASS P	ROTOTYPI	E W	LOWPASS PROTOTYPE FILTER OR ITS BANDPASS EQUIVALENT
	PROGRAM	ŧ	•• ••	FILTERIS APRIL 19, 1980
	REVISION	18	•	23.
	PREPARED	E0 8Y	•	
				MOTORULA GOVERNMENT ELECTRONICS DIV. TEMPE, AMIZUNA 85282
INPUT				NUMBER OF FREQUENCY SAMPLES
)	80	DRAD	•	NORMALIZED RADIAN FREQUENCY INCHEMENT
	₹ 4	RACIN		INITIAL RADIAN FREQUENCY FRACTIONAL BANDEIDTH AT FINAL IF
	ב	LPBP	•	
	į	i		0 : LUWPASS
	•			1 : BANDPASS
	30 d	BWFCTR		BANDWIDTH FACTOR
	Ž	NPOL	•	PULES
	Por	يد	•	
	.		•	SAMPLED TRANSFER FUNCTION
COMPLEX COMPLEX DIMENSIO	HERENERS BOL (1) . H (1)	DEN.H 1).H(1)	H M H	HERRICAL HOLVS.DEN.H
ADJUST 1 COMPUTE	ADJUST INCREMENT COMPUTE SAMPLED 1	NT AND INITIAL D TRANSFER FUNC	INI	ADJUST INCHEMENT AND INITIAL RADIAN FREQUENCY COMPUTE SAMPLED TRANSFER FUNCTION
ORADLE (RA PADIE (RA DO 10 18	DRADLEO.5*URAD/BWFCTR RADI=(RADIN/2-BWOFF)/ BO 10 1=1.NF	5*0KAD/BWFCTH 01N/2-8W0FF)/BW 1*NF	34.5	DRAOLEO.5*URAD/BWFCTR RADI=(RADIN/2-8WOFF)/8WFCTR-DRAOL DO 10 I=1.NF
KAD#KA H([) #]	MADEKADI•I•DKADL H(I)=1	7		

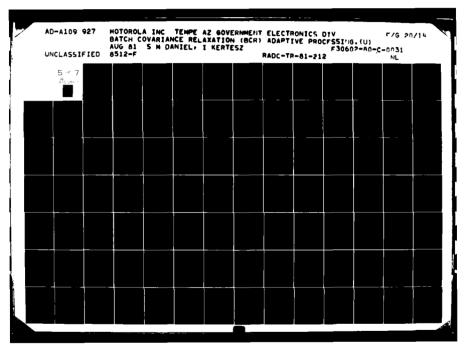
V-142

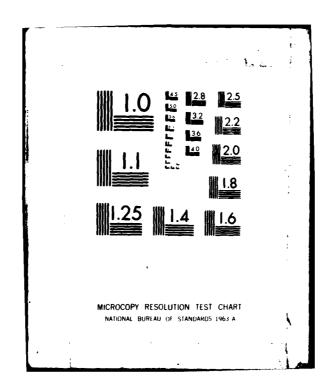
N. A.

0000	ESSESSESSESSESSESSESSESSESSESSESSESSESS	Z	HRHHH ORMALI AT	ZED C UISCR	HANNE ETE F	EVALUATION OF NORMALIZED CHANNEL BASEBAND SAMPLED TRANSFEH FUNCTION AT DISCRETE HADIAN FREQUENCIES
000		LINEA	LINEAR ANTENNA WITH SPEI	NNA A	RRAY 1ED (ANTENNA ARRAY AND RECEIVER CHARACTERISTICS WITH SPEIFIED CHANNEL AND PORT DELAYS
000		PROGRAM ONIGINAL	PROGRAM ON IGINAL PERISTON	** ** *	KA A	CHANNEL 15 HAY A 1980
U U		4 L	N 0 1 0 1	••	2	ć
00000		PREP	prepared	₩ 84	S. HAL HOT	S. M. DANIEL & I. KERTESZ Hauar Systems analysis group Motorola government electronics div. Tempe, arizona 85282
U U	INPUT	-	NEL		Ş	NUMBER OF ELEMENTS IN LINEAR ARRAY
U			- 1001 -	•	9	LOCATION (NUMBER) OF FIRST ELEMENT
U (, אי	•	Ž į	
U			0 1	8 1	ELE	ELEMENI SEMAKAIJON MACTOK AJIMITA ANGIR 1066) OK INCIDENCE
ے ر			CTAU	•	Z CZ	NORMALIZED CHANNEL DELAY
· u			PTAU	•	Š	NORMALIZED PORT DELAY
U			J.	•	Ž	NUMBER OF FREQUENCY SAMPLES
U			KADIN	•	Z	INITIAL HADIAN FREQUENCY
ن			DHAD	•	Š	NORMALIZED RADIAN FREGUENCY INCREMENT
U			BWFCTR	•	BA	BANDWIDTH FACTOR
U			BWOFF	•	8 A	FFSET FACTOR
U		_	FBKF	•	FR	FRACTIONAL BANDWIDTH AT RF
v			ĩ	•	PEC	RECEIVER SAMPLED TRANSFER FUNCTION
U (***************************************		1			MOTEONIA OPPOSED OF ICHES ISSUES
ے ر		H H H H				COLTCO : TO TO CARTEL SAMPLES OF THE COLTCO TO SECURITY TO CACTOR OF THE SECURITY TO SECURITY
,	DOUBLE	COMPLEX	EX			
	COMPLEX HR.H	I SE				
	DIMENSION HH(1) .H(1) .AL(1)	NO HE	(1) .H(1) . AL	:	
	DATA P1/3.14159265/	1/3.14	159265	•		
	RATIO=FBHF/BWFCTR	BRF/B	WFCTR			
	DRADL=RATIO+DRAD/2	SAT 10.	DRAD/2			
	RAD1=1	RATIO	* (HADI	N/2-8	MOFF)	RAD1#1+RATIU+(HADIN/2-BWOFF)-DHAUL

EVALUATION OF BASEBAND CHANNEL SAMPLED TRANSFER FUNCTION CHECH+AL (J) *DCMPLX (DCOS (ARG) ,DSIN (ARG)) CHECH+DCMPLX (DCOS (ARG) .DSIN (ARG)) PDSTH#PI+D0+SIN(TH+PI/180) ARG=-RAD+ (CTAU+PTAU) RAD=RAD1+I*URADL ARGO#POSTH*RAD DO 20 J#1.NEL H(I)*CH*HR(I) DO 10 I=1.NF ARG=ARGO*LOC LOC=LOC1-1 LOC=LOC+1 CONTINUE RETURN CHEO 20 ລິວ **U** U U

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FORMATIGK. FIELD PATTERN BEFORE AND AFTER BCR ADAPTATION ABOUT INT COMMON /BCRP4/ S0(256),W(20),WIT(21,20),SC(256),AS0(256),ASC(256) COMMON /BCRP3/ BWFCTR(21) . BWOFF (21) . PTAU(21) . DO. NEL (21) . LOC1(21) FORMAT(15X, MAIN BEAM PATTEMN BEFONE AND AFTEM BCR ADAPTATION .. / COMMON /BCRP1/ POL(6).FBIF.FBRF.HADKNG.RADIN.DRAD.NPOL.LPBP.NF COMMON /BCRP2/ AM0(64.20).AMC(64.20).TH(20).CTAU(20).ISC(20) RAUAR SYSTEMS ANALYSIS GROUP MOTORULA GOVERNMENT ELECTRONICS DIV. ELECTRIC FIELD AMPLITUDE PATTERN BEFORE ADAPTATION ELECTRIC FIELD AMPLITUDE PATTERN COMPUTATION OF ELECTRIC FIELS AMPLITUDE PATTERNS COMMON /BCRPS/ NIH, THETA (64,21), AEB (64,21), AEA (64,21) FORMAT (/.31x. MAIN FIELD PATTERN: ./.31x.18(!-!))
FORMAT (/.29x. COMPOSITE FIELD PATTERN: ./.29x.23('-!)) I. KERTESZ ABOUT INTERFERENCE ANGLES OF ARRIVAL HEFORE AND AFTEN BCR ADAPTATION TEMPE, AHIZONA 85282 -. X (256) . AL (1001) . ISH (20) . NS. NKX . ITER . ITER ! 4. 1980 AFTER ADAPTATION JANUARY 31. 1981 J SYSTEM PARAMETERS IN COMMON S. M. DANIEL FIELDIS AUGUST -ERFERENCE + (4+/+6X+68(+++)) COMPLEX SO.M.WIT.SC.POL -. ISP (20) . IOP (21) .NPM1 ВΥ DATA P1/3.14159265/ FORMAT (1X.79(*-+1) PREPARED SUBROUTINE FILLD REVISION DOUBLE COMPLEX E OHIGINAL -. IDC (20) .NCHNLS AEB PROGRAM FORMAT (8F 10.5) -.15X,49(1-1)) FORMAT (1H1) OUTPUT INPUT 200 400 700 20. 25. 72. . 6 9 - 2 2 6 * 50 0 7 8 6 23. 29. 32. ÷ • 30. 34. 36. .04

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OVER A 0.25 DEG RANGE ABOUT EACH INTERFERENCE ANGLE OF ARRIVAL
                                                                                                                   COMPUTE ELECTRIC FIELD PATTERNS BEFORE AND AFTER ADAPTATION
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  (THETA(IA.IC), AEB(IA, IC), IA=1,NTH)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              (THETA (IA. IC) . AEA (IA. IC) . IA=1.NTH)
                                                                                                                                                                                                                                                                                                                                                 E=E+AL (IL) *DCMPLX (DCOS (ARG) *DSIN (ARG))
                                                                                                                                                                                                                                                                                                                                                                                                                                          E=E+W(IP) +OCMPLX (DCOS(ARG) +DSIN(ARG))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     IF (IC. LT. NCP1) WRITE (108, 300) IDC (IC)
                                                                                                                                                                    CALL ANTWT (NEL(1) .LOC1(1) .AL.0)
                                                                                                                                                                                                                                                                                                                                                                                                                            ARGELOCI (IPP1) *ARGI-PTAU(IPP1)
                                                                                                                                                                                                                                                                                                                                                                AEB (14.1C) =20*AL0610 (CABS (E))
                                                                                                                                                                                                                                                                                                                                                                                                                                                        AEA (1A.1C) =20*AL0G10 (CABS (E))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      WRITE (108+400)
                                                                                                                                                  INCLUDING MAIN BEAM EFFECT
                                                                                                                                                                                                           IF(IC.LT.NCP1) THE=TH(IC)
IF(IC.EQ.NCP1) THE=0
                                                                                                                                                                                                                                                                                                                                                                               THETA (IA. IC) = THE/CONV
                                                                                                                                                                                                                                                                                                                                     ARG= (LOC0+1L) +ARG1
                                                                                                                                                                                                                                          THEOSCONVOTHEOTHO
                                                                                                                                                                                                                                                                                                                      DO 30 IL=1.NEL(1)
                                                                                                                                                                                                                                                                                       ARGI SPI SIN (THE)
                                                                                                                                                                                              DO 10 IC=1.NCP1
                                                                                                                                                                                                                                                                         THE #THEO . I A . DTH
                                                                                                                                                                                                                                                                                                                                                                                             DO 40 IPEL NPMI
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    IF (IC.EO.NCP1)
                                                           TH08-RTH/2-DTH
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    WHITE (108.700)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                         WRITE (108.100)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        WRITE (108.200)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   WRITE (108.500)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  #RITE (108,700)
                                                                                        LOC0=LOC1(1)-1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                WRITE (108.200)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  #HITE (108,600)
                                                                          NCP | BNCHNLS+1
CONVEP1/180
                                           DINERTHINIT
             RTH=CONV/4
                                                                                                                                                                                                                                                                                                                                                                                                             1001=1001
                             NTHEST
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COMMON /BCHP4/ S0(256),W(20),WIT(21,20),SC(256),AS0(256),ASC(256) COMMON /BCRP3/ BWFCTR(21), BWOFF(21), PTAU(21), DO.NEL(21), LOC1(21) MAIN AND COMPOSITE CHANNEL AMPLITUDE RESPONSES MAIN AND COMPOSITE ELECTIC FIELD AMPLITUDES ABOUT INTERFERENCES COMMON /BCRP1/ PUL(61.FBIF.FBRF.HAURNG.HADIN.DRAD.NPOL.LPBP.NF COMMON /BCRP2/ AHO(64.20).AHC(64.20).TH(20).CTAU(20).ISC(20) MOTOROLA GOVERNMENT ELECTRONICS DIV. COMPOSITE ARRAY OF ADAPTIVE WEIGHT ACTUAL NUMBER OF SIGNAL SAMPLES RADAR SYSTEMS ANALYSIS GROUP COMMON /BCRPS/ NTH.TMETA(64,21),AEB(64,21),AEA(64.21) S. M. DANIEL BCR-ADAPTED COMBINED SIGNAL MAIN AND ADAPTED SIGNAL AMPLITUDE EVOLUTION OF ADAPTIVE WEIGHTS TEMPE. ARIZONA 85282 6. 1980 2. 1981 -• X (256) • AL (1001) • IS# (20) •NS•NWX • ITER, ITER MAIN-POHT SIGNAL J GRAPHICAL OUTPUT I. KERTESZ SEPTEMBER FEBRUARY **ITERATES** PLOTS:S -------------DIMENSION WW(420) . WR(21) . WI(21) PLOT AMPLITUDES OF SO AND SC INDICATED PLOTS COMPLEX SO.SC.W.WIT.WW.PUL -. [SP(20).10P(21),NPM] ₩ DATA DMAX /1.0E10/ SUBROUTINE PLOTS PREPARED OR I GINAL REVISION -- IOC (20) .NCHNLS PHUGRAM S 20 S DO 10 15=1.NS • X(1S) *1S OUTPUT 0 Uυ 10. 11: ÷: ċ • 17. 20. 23. 24. 25. 28. 29. 6 26. 30. 31. 33. 39. 36. 38. •

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IF(IC.EU.NCMMLS) II=-II
CALL ALLPLUT(3.NF.II.R1.K2.D1.D2.X.AM0(1.IC).AMC(1.IC))
                                                                                                                                                                                                                                                                                                            PLOT MAIN AND COMPOSITE CHANNEL AMPLITUDE RESPONSES
                                                                 CALL TRANGE (NS. 1.01.02.4SC)
CALL ALLPLOT (1.NS. 0.81.82.01.02.X.ASn. ASC)
                                                                                                                                                                                                                                                                                      CALL ALLPLUT (2. ITERI.II.-D.D.-D.D.HR.WI)
                                                                                                                                                                                                                                                                                                                                                                                                                                  CALL TRANGE (NF.1.D1.D2.AMO(1.1C))
CALL TRANGE (NF.1.D1.D2.AMC(1.1C))
                                                                                         PLUT ADAPTIVE WEIGHT EVOLUTION
                              CALL TRANGE (NS.1.D1.D2.ASO)
                                                                                                                                                                                                        CALL TRANGE (K+1+D1+D2+WW)
                                                                                                                                                                                                                    DEAMAX1 (ABS (D1) , ABS (D2))
                                                                                                                                                                                                                                                                 WILL BAIMAGIMIT (1.3)
                                                                                                                                                                                                                                                      WR(I)=REAL(WIT(I.J))
                                                                                                                                                                                                                                                                             IF (J.E0.NPM]) 11=-1
                                                                                                                                                                                                                                                                                                                                                              X(IF) =RAD . IF * DHAD
                                                                                                                                                                                                                                                                                                                                                                                                00 60 IC=1.NCHNLS
                                                                                                                                                                                                                               00 40 Jel.NPMl
00 30 Iel.ITEMl
                                                                                                                                                 DO 20 I*1. ITERI
                                                                                                                                                                                                                                                                                                                                       RAD=RADIN-DHAD
                                                                                                                                     DO 20 J#1.NPM1
                                                                                                                                                                        ME(K) SEIT (I+)
                                                                                                                                                                                                                                                                                                                                                   DO 50 IFE1.NF
                                                                                                                                                                                                                                                                                                                                                                                                                                                          []=[0C(]C)
                                                                                                                                                                                                                                                                                                                                                                                     R2=X (NF)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             CONTINUE
                                                                                                                                                                                                                                                                                                                                                                            R1 = X (1)
                                                                                                                                                                                                                                                                                                                                                                                                            D1=DMAX
                                                                                                     D1=DMAX
          DISOMAX
                                                                                                                                                                                                                                                                                                                                                                                                                          02=-01
                                                                                                                  02=-01
                      02=-01
                                                                                                                                                              K=K+1
                                                                                                                                                                                      K=2*K
RZENS
                                                                                                                                                                                                  0=11
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CALL ALLPLOT(IPLACE,NTH.II.HI.R2.DI.D2.THETA(1.1C).AEB(1.1C) PLOT MAIN AND COMPOSITE ELECTRIC FIELD ABOUT INTERFERENCES CALL TRANGE (NTH-1-01-02-AEB(1-1C))
CALL TRANGE (NTH-1-01-02-AEA(1-1C)) IF (IC.EQ.NCHNLS) IIS-II IF (IC.EQ.NCHPI) IPLACES DO 70 IC=1.NCHP1 R1=THETA(1.IC) R2=THETA (NTH. IC) NCHP1 BNCHNLS+1 CONTINUE 11=10c(1c) IPLACE*4 D1=DMAX 02=-01 RETURN 20 $\mathbf{U} \mathbf{U} \mathbf{U}$ 88. 89. 90. 91. 92. 93. 3 95. 96. 97. 66 100. 03. 106.

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Å • • •	ပ်ပပပ	PROGRAM : ALLPLOTIS ORIGINAL : AUGUST 20. 1980 REVISION : FEBRUARY 3. 1981
12. 13. 13.	ပပမဲ့ပပ	Y I S. M. DANIEL & I. KE RADAR SYSTEMS ANALYSIS MOTOROLA GOVERNMENT EL TEMPE, ARIZONA 85282
	; , , , , , ,	INPUT : IPLACE - PLOT SELECTAR 1 : TITLE PAGE AND SIGNAL AMPLITUDES 2 : FYGLITTON OF WFIGHTS
	ပုံပပ	3 1 MAIN AND COMPOSITE CHANNEL AMPLITUDE RESPONSES
22:	، ن د	S : MAIN BEAN FIELD PATTERN COASE INTERED FALLERN
, , , ,	ب د	SPARE
5	Ų	1.02 - SPARE REAL
25.	u c	X = ABSCISSA <
27.	رىر	•
88.	ن ن	
32.33.		DATA HV/630610310280250./ DIMENSION X(1).Y1(1).Y2(1).LABM(60).LAB20(20).LAB12(12) DIMENSION LARFL(15.8)
34.		DATA LABEL/
35.		•
37°		· •
38.		4. • ADVANCED TECHNOLOGY AND SYSTEMS ANALYSIS 6. • ACFD MOTOBOLA INC GFD
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42. 43.		8. TIELD PATIENN ABOUT INTERPENCE NEIGHBORNOOUS

000	INTEGER ICAS(4)/100.600.100.600/.1GXF(4)/450.950.450.950/ INTEGER IGAS(4)/100.600.100.100/.1GYF(4)/700.700.340.340/ - IGYS(4)/460.460.100.100/.1GYF(4)/700.700.340.340/ - IGP(4)/175.675.175.675/.1GQ(4)/712.712.360.360/ - NGP(4)/135.635.135.635/.NGQ(4)/395.395.20.20/ FORMAT(8MCHANNEL .14) FORMAT(F6.1.5H TO .F6.1.3H DB)
	E PLOT
	GOTO (1000,2000,3000,4000), IPLACE
! 	INITIALIZE PLOTTING
1000	12=0 13=0 15=0 CALL TIMEDAT
: 	12
<u>.</u>	CALL TYPEW(60,LABEL(1,I),10 CALL TYPEW(16,ITDATE,380,.2)
	CALL TTYPEA(16.ITDATE.700.0) CALL TTYPEA(40.40H CALL TTYPEA(40.40H
	-200-390) CALL TPLOTI(011.NX.R1.R2.D1.D2.128.896.470.720.X.Y1) CALL TTYPEA(40.40H -200-20)
•	CALL TPLOTI(011.NX.R1.M2.D1.D2.128.896.100.350.X.Y2) CALL TRING RETURN
i :	PLOT EVOLUTION OF ADAPTIVE WEIGHTS
2000	15C=1 12=12+1 1F(12-NE-

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PLOT MAIN BEAM ELECTRIC FIELD PATTERN BEFORE AND AFTER ADAPTATION
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    TIYPEA(37,37HMAIN BEAM BEFORE AND AFTER ADAPTATION. 260.40)
                                                                                                                   PLOT ELECTRIC FIELD PATTERN ABOUT INTERFERENCE NEIGHBORHOODS
                                                                                                                                                                                                                                                                                                                                                                                                                                      CALL TPLOT1(-1.1.NX.H1,RZ.D1,D2.1GXS(13).1GXF(13).1GYS(13)
                                                                                                                                                                                                                                                                                                                                                                            CALL TPLOT1(0.0.NX,R1.R2.D1.D2.1GXS(13).1GXF(13).1GYS(13)
                             CALL TTYPEA(30,30H EVOLUTION OF ADAPTIVE WEIGHTS,280,60)
                                           CALL TPLOTI(ISC.0.NX.RI.R2.DI.D2.200.800.160.760.X.YI)
                                                                                                     PLOT MAIN AND COMPOSITE CHANNEL AMPLITUDE HESPUNSES
                                                                                                                                                                                                                                                                                     CALL TTYPEA(60.LABEL(1.1LAB1),100.75n)
CALL TTYPEA(60.LABEL(1.1LAB2),100.730)
                                                                                                                                                                                                                                                                                                                                                              CALL TTYPEA(12, LAB12, 16P(13), 16Q(13))
                                                                                                                                                                                                                                                                                                                                                                                                                          CALL TTYPEA(20.LAB20.NGP(I3),NGQ(I3))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                    IF(II.LT.0.0R.13.EQ.4) GUTO 3300
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      TTYPEA(16,1TDATE,700.0)
CALL TTYPEA(16.ITDATE.700.0)
                                                                                                                                                                                                                                                                        TTYPEA(16.1TDATE.700.0)
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                                                                                                                                                                                                                                                                                                                                                                                                                                                      • IGYF (I3) • X • Y2)
                                                                                                                                                                                                                                                                                                                                                                                                           ENCODE (20.200.LAB20) RL,RH
                                                                                                                                                                                                                                                                                                                                                ENCODE (12.100.LAB12) 11A
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                                                           IF (II.LT.0) CALL TRING
                                                                                                                                                                                                                                           [F(13.NE.1) GOTO 3200
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CALL TPLOTI(0.0.NX.RI.R2.DI.D2.120.970.120.780.X.YI)
CALL TPLOTI(-1.4.NX.RI.R2.DI.D2.120.970.120.780.X.Y2)
CALL TRING

RETURN

130. 132. 133. 134.

V-153

COMPOSITE	SUBPROGRAM TTEKS
PROGRAM T	
ARE RELATION THE NAME THE CONTE	PROGRAM TTEKS IS A COLLECTION OF SIMPLE SUBROUTINES, ALL OF WHICH ARE RELATED TO TEKTRONIX-USER PROGRAMS, THEY ARE COMPILED UNDER THE NAME TTEKS, TO PRODUCE THE BINARY LIBRARY TTEKS:8
vi S &	SUBPROGRAM : TTEKS:S ORIGINAL : AUGUST. 1980 REVISION : FEBRUARY 23. 1981
	PREPARED BY : S. M. DANIEL & I. KERTESZ Radar Systems analysis group Moturola Government Electronics DIV. Tempe, arizona 85282
MEMPER	DESCRIPTION
TCLEAR	
DIASAU	COORDINATES LINE BEINEEN TWO GIVEN WINDOW
TORANTO	DRAWS A SOLID LINE BETWEEN TWO GIVEN WINDOW COORDINA-
TINIT	INITIALIZES OR RESETS THE PLOTTER
10,011	
TRANGI	GIVES MINIMUM AND MAXIMUM VALUES OF AN ARRAY
TRING	GIVES THREE BELLS AND ASKS FOR "RETURN" COMMAND
TTICKER	HORIZONTAL AND VERTICAL
1	TES
TTICKE	PLACES HORIZONTAL TICK-MARK AT THE GIVEN WINDOW COORDINATES
TTICKV	PLACES VERTICAL TICK-MARK AT THE GIVEN WINDOW COORDI-
TTYDEA	NATES TYPES A 1 TO AO CHABASTED MESSAGE AT THE GIVEN
	ALUTE (SCREEN) COORDINATES
TTYPEW	TYPES A 1 TO 80-CHARACTER MESSAGE AT THE GIVEN
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ALL OF THE ENTRYRETURN GROUPS IN SUBROUTINE TTEK ARE IN- DEPENDENT, AND CAN BE REPLACED OR MODIFIED WITHOUT AFFECTING THE OTHERS. THEY WERE PLACED IN ONE SUBROUTINE ONLY TO REDUCE THE OVERHEAD ASSOCIATED WITH MANY SUBROUTINES.	1980 Y 16• 1981		BED FOR EACH ENTRY SEPARATELY		ITEKIO.IUSER LIBRARY	DIMENSION MESSAGE (NC) . LABEL (80) REAL Y(1) ENTRY ITYPEA (NC, MESSAGE, IM, IV)
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CALL CALL CALL CALL CALL CALL CALL CALL	DH # H - 7, CALL DRAWA(RH,V) CALL DRAWA(RH,V) CALL DRAWA(H,V) CALL DRAWA(H,DV) RETURN CALL DRAWA(H,DV) RETURN CALL DRAWA(RH,V) CA	VERTICAL COORDINATE				S ARE NEEDED.	14 273	Ì
			DV CALL CALL RETUR	ENTRY DH = H CALL D	ENTRY TCLEAR TCLEAR IS USED TO CLEAR	ITE-MODE. ERASE HOME ANMODE	ENTRY TINIT INITIALIZE OR RESET THE I	CALL INITIONS

I'm of the training

CALL TERM(1,1024) CALL BINITT RETURN

lig t ENTRY TRING

THREE BELLS AND A POKE SOUNDS THREE BELLS THEN PAUSES UNTIL A PRETURN. OR 'ENTER' RESPONSE FROM THE OPERATOR IS RECEIVED.

CALL BELL CALL BELL CALL BELL CALL TINPUT(K) RETURN END

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216. 217. 218. 219. 220. 227. 228. 228. 230. 231.

10. C SUBROUTINE TRIOTICIDED TO PLOT ONE OR MORE CURY SUBROUTINE TRIATION TELEFECT WHEN SPECIFIED. 10. C SUBROUTINE TRIATION THEN SPECIFIED. 11. C SUBROUTINE TRIATION THEN SPECIFIED. 12. C SUBROUTINE TRIATION THEN SPECIFIED. 13. C SUBROUTINE TRIATION THEN SPECIFIED. 14. C SAMPLE-AND-HOLD EFFECT WHEN SPECIFIED. 15. C SAMPLE-AND-HOLD EFFECT WHEN SPECIFIED. 16. C SAMPLE SAMPLE SAMPLE. 17. C SAMPLE SAMPLE SAMPLE. 18. C SAMPLE SAMPLE SAMPLE. 19. C SAMPLE SAMPLE SAMPLE SAMPLE SAMPLE SAMPLE SAMPLE SAMPLE. 10. C SAMPLE	SUBROUTINE TPLOTICIPLOTILINE, NP. XS. XB. YS. YS. XF. IYS. IYF. XY. YS. YB. SUBROUTINE TO PLOT ONE OR MORE CURVES ON THE SAME GRID. SUBROUTINE TPLOTICIPLO SELOW WITHOUT A MEADER. IS A REPLACEMENT FOR THE TEKTRONIX SUBROUTINE OF SAME NAME TO PRODUCE THE SAMPLE-AND-HOLD EFFECT WHEN SPECIFIED. ORIGINAL : AUGUST. 1980 REVISION : FERRUARY 23, 1981 PREPARED BY : S. M. DANIEL. 6. C. WANG. & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP HOTORYLA GOVERNMENT ELECTRONICS DIV. TEMPE. ARIZONA 85282 INPUT : IPLOT - PLOT OFTION: TO PLINTS O USE THE INPUT X AND Y LIMITS ILINE - LINE TYPE: O USE THE INPUT X AND Y LIMITS ILINE - LINE TYPE: O SOLID XS. XB - X-GRID LIMITS ILXS. IXF - X (HORIZONTAL) GRAPH LIMITS IN SCREEN CORRINGED AND HOLD STYLE IXS. IXF - X (HORIZONTAL) GRAPH LIMITS IN SCREEN CORRINGED AND THE STATE OF THE STAT
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44. 2000 CALL DLIMY(YS.YB)
45. CALL CHECK(X.Y)
47. CALL LINE(ILINE)
49. RETURN
50. 3000 CALL LINE(ILINE)
51. CALL NPTS(NP)
52. CALL CPLOT(X.Y)
52. CALL CPLOT(X.Y)
53. RETURN
54. IF (I.NE.1) CALL DRAWA(X.YOLD) 7 CALL DRAWA(X.Y)
54. IF (I.NE.1) CALL DRAWA(X.YOLD) 7 CALL DRAWA(X.Y)
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Table 2-20. Functional Description of the Modules Comprising BCRP

	1.000		į	FUNCTIONAL DESCRIPTION OF BCRP SOURCE MODULES
, m	8	•		
1 , (9			
	8	1	•	MAIN EXECUTIVE PROGRAM. IT CALLS OTHER EXECUTIVE AND DEDICATED
-	6			SUBPROGRAMS TO COMPUTE DATA INTENDED FOR PLOTTING. THESE DATA
•	8.000			CHARACTERIZE THE ANTENNA-RECEIVER SYSTEM. SCENARIO. AND THE APP-
•	Ş			LIED BCR TECHNIQUE.
10.	8	,		
=======================================	9	BCRPSET1S	•	EXECUTIVE SUBPROGRAM. IT IS DESIGNED TO READ FROM THE INPUT DA-
12 -	8			TA FILE, BCRPID, USING THE GENERAL INPUT AND OUTPUT SUBROUTINES
- E	8			RW. RWIRC. AND SKIPR IN ACCORDANCE TO PRESET FORMAT. ALL DATA IS
- ::	1.00			MADE AVAILABLE TO APPROPRIATE SUBROUTINES THROUGH COMMON BLOCKS.
15 -	5.00			
16 -	9.00	RVIS	•	GENERAL SUBPROGRAM. (DEFINED IN SIGGEN.)
17 -	7.00			
19	9.00	RWINCIS		GENERAL SUBPROGRAM, (DEFINED IN SIGGEN.)
- 61	9.00			
- 02	9.00	SKIPRIS	•	GENERAL SUBPROGRAM. (DEFINED IN SIGGEN.)
22	1.00			
22 -	2.00	CHPCHNL 1S		I. THIS SUBPROGRAM WILL COMPUTE THE
23 -	3.00			RESPONSE BEFORE AND AFTER ADA
24 -	4.00			ON USING THE ADAPTIVE WEIGHTS SUPPLIED BY THE BCR PROCESS. IT
S S	5.00			WILL MAKE AVAILABLE THE MAGNITUDE OF THESE AMPLITUDE RESPONSES
56 -	6.00			THROUGH THE COMMON BLOCKS.
- 12	7.00			
- 92	8	ANTWTIS	•	DEDICATED SUBPROGRAM. (DEFINED IN SIGGEN.)
&	9.00			
96	0.00	FILTERIS	•	DEDICATED SUBPROGRAM. (DEFINED IN SIGGEN.)
3	.0			
32 -	2.00	CHANNEL 1S	•	DEDICATED SUBPROGRAM. (DEFINED IN SIGGEN.)
33	3.00			
ä	* 000	FIELDIS	•	DEDICATED SUBPROGRAM. THIS SUBPROGRAM WILL COMPUTE THE ELECTRIC
35	9.6			FIELD PATTERN IN THE NEIGHBORMOOD OF EACH INTERFERENCE BEFORE AND
98	9.00			AFTER ADAPTATION, AND MAKE AVAILABLE THE MAGNITUDE OF THESE ELEC-
37 -	7.00 0			TRIC FIELDS AND THAT OF THE MAIN BEAM THROUGH COMMON RLOCKS.
98	Š			
39	9	PL0TS:S	ŧ	EXECUTIVE SURPROGRAM. THIS SUBPROGRAM EXTRACTS THE DATA FROM THE
1 0 1				COMMON BLOCKS. AND COORDINATES THE PLOTTING ACTIVITY THROUGH THE
-	Õ			DEDICATED PLOTTING ROUTINES.

AMPLITUDES IN THE NEGIHBORHOOD OF THE INTERFERENCES. AND THE MAIN BEAM FIELD MAGNITUDE. THIS SUBPROGRAM MAKES REFERENCES TO THE BY AN EXECUTIVE SUBPROGRAM SUCH AS PLOTSIS TO PLOT ACCORDING TO A BUILT-IN FORMAT THE FOLLOWING RCR SIMULATION RESULTS: TITLE-PA-GE. EVOLUTION OF THE WEIGHTS. MAIN AND COMPOSITE CHANNEL TRANSFER COMPUTER SYSTEM LIBRARY FOR THE FUNCTION TIMEDATE, AND THE TEK-GENERAL SUBPROGRAM. THIS SUBPROGRAM IS A COLLECTION OF UTILITY ROUTINES WHICH ARE REFERENCED BY TEKTRONIX PLUBLING-RELATED SUBPROGRAM MAKES REFERENCES TO THE COMPUTER SYSTEMOGRAMS. FUNCTION AMPLITUDES BEFORE AND AFTER ADAPTATION, ELECTRIC FIELD THIS SUBPROGRAM IS DESIGNED TO BE CALLED TEK10.1USER LIBHARY. DEDICATED SUBPROGRAM. TRONIX USER LIBRARY. TEMIS ı ALLPLOTIS TTEKSIS 000.41 43.000 15.000 16.000 52,000 53.000 17.000 4A.000 49.000 50.000 51.000 54.000 55.000 56.000 57.000 3 Š 9 -9 0 25 25 53 55.5

Table 2-21. JCL Program, JCLBCRP:BL

OVER BCRP1L # ITEK10.1USER 1JOB 1269,DANIEL (8512),7,8LD690 1LIMIT (TIME,2),(U0,40),(C0,35),(ACCOUNT)JCLBCRPIBL....... OVER BCRP18 SKIPR CHANNEL 18, 1269 ALLPLOT18,1269 TTEKS18,1269 FILTER18,1269 RWIRC18.1269 CMPCHNL 18.1269 BCRPSET18,1269 ANTWT:8,1269 ANTWT:8.1269 TTEKS18.1269 BCRPMAINIB. 1269 FIELD:8.1269 PLOTS18,1269 RW18.1269 ILYNX BCRP18

!BCRP:L.

carries out the execution. Only the graphical activity will be apparent on the terminal. As each page or picture is completed, a series of 3 closely spaced but distinct beeps will be heard, followed by a pause. If a permanent (hard-copy) is desired, it should be made at this time, since the picture will remain on the screen until the proper response is given by the operator. The required response is actuating the "RETURN" or "ENTER" key. The 3 beeps constitute a warning to copy the screen or lose it.

After the proper response, the screen is blanked and a new picture begins to form, again followed by 3 beeps when completed. When all pictures have been drawn, the word "EXIT" appears, meaning the execution is properly terminated. The complete graphical output obtained this way for the benchtest example is shown in Figure 2-8.

2.4.4 Output File - BCRP:0

The output data file, BCRP:O is shown in Table 2-22. It was produced by executing the program BCRP:L with the input data BCRP:D. Note that the front part of the BCRP:O output is simply a repetition of the input data file BCRPLD. This is followed by data to be plotted, as shown in Figure 2-8.

The title page of the CRT-plots identifies the program and the date and time of execution. This ties the pictures to the printed data, since that, too, is dated by the operating system. This is important because the system, scenario, and BCR description are not always discernible from these pictures.

The next frame contains the original and combined signal plots. These are actually the amplitudes of the Port O signal, and the combined port signal, respectively. The signals were read as part of the input data and the amplitudes were found in BCRPSET via an appropriately simple operation.

The next frame presents the two-step iterative evolution of the adaptive weights in a common complex plane. Initial value and weight iterates, $w^0 = 0$, w^1 and w^2 are read from the "composite weight-vector array" input. Since $w^0 = 0$, all weight-vector components begin at the origin, progress in various directions from there according to w^1 and terminate at w^2 . The breaks in the weight-component loci indicate their values at the first iteration. The end points constitute their values at the second iteration.

The channel and field graphs are plotted in groups of four per frame. As such, in general, more than one frame may be needed for these graphs. The main and composite channel transfer function amplitudes are plotted for each interference. In these and subsequent plots, the solid line indicates the original response while the dotted one stands for the adapted one. The abscissa is the normalized radian frequency range, and the values in dB below each plot indicate the amplitude levels before and after adaptation at the center frequency. The data for these plots are produced by CMPCHNL.

Title Page

ADAPTIVE PROCESSING BCR

BENCHTEST EXAMPLE (See Figure 2-2) SOURCES

2 (10, 45°)

AUXILIARY PORTS :

0.1%

RF BANDWIDTH

: 1/PORT TAP WEIGHTS

SIMULATION BY : S. M. DANIEL & I. KERTESZ ADVANCED TECHNOLOGY AND SYSTEMS ANALYSIS MOTOROLA, INC. - GED

13:03 FEB 14, '81

Figure 2-8

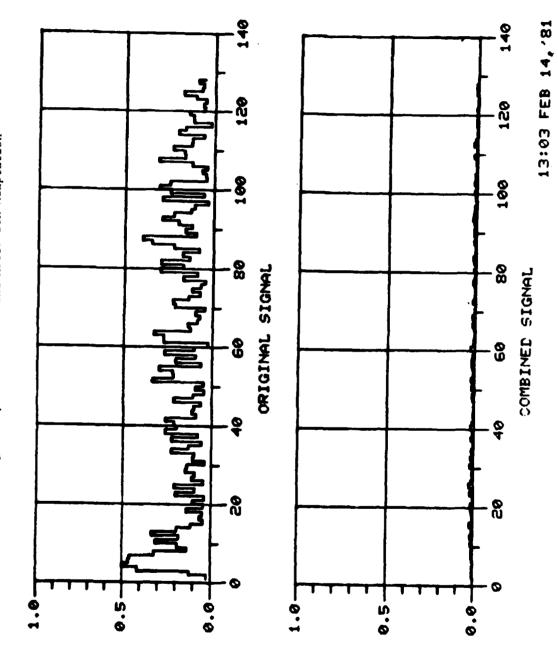
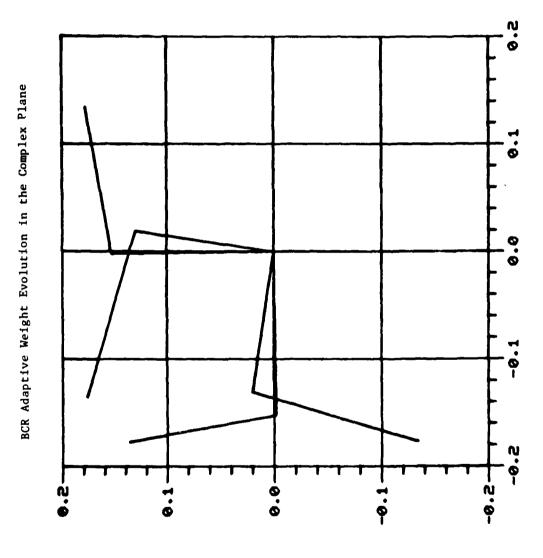


Figure 2-8 (Cont'd)



EVOLUTION OF ADAPTIVE WEIGHTS

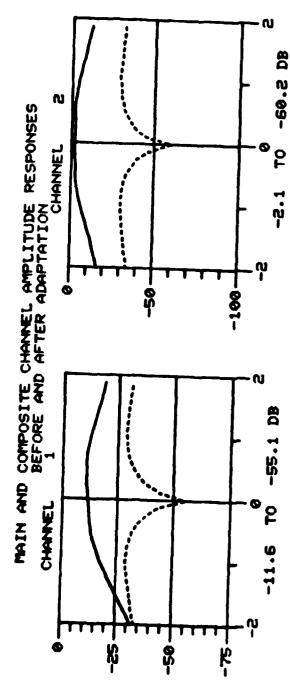
13:03 FEB 14, '81

Figure 2-8 (Cont'd)

Figure 2-8 (Cont'd)

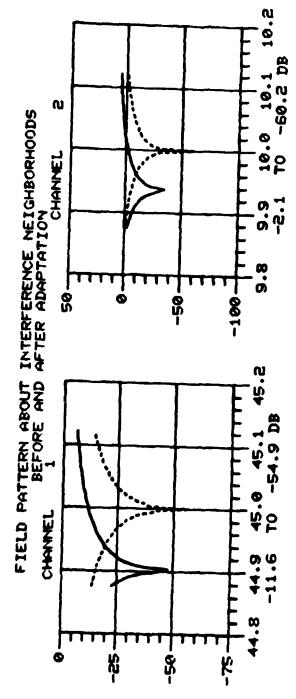


Ĭ

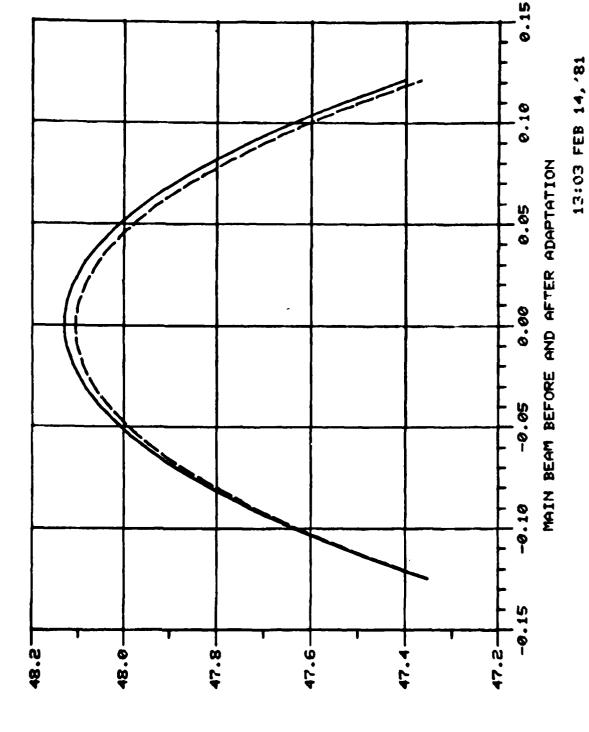


V-165-3

Field Pattern Amplitudes Over 0.25 Neighborhoods About Source Angles of Arríval at RF Center



Main Beam Field Pattern Amplitude at Center RF Frequency, Before and After BCR Adaptation



v-165-5

Table 2-22. Output Data File of the BCR Plotting Program, BCRP:0 Benchtest Example (See Figure 2-2)

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SPECIFICATION OF SYSTEM PARAMETERS

PRINT OPTIONS	LION	5				
I CANI		MAIN ANTENNA ARRAY WEIGHTING	••	C		
IWRAP	•	RECEIVER AMPLITUDE AND PHASE	•••	• •		
IWRI	•	RECEIVER IMPULSE RESPONSE	•	• •		
INCAP	•	CHANNEL AMPLITUDE AND PHASE	••	0		
INCI	•	CHANNEL IMPULSE RESPONSE	••	0		
INSC	•	INDIVIDUAL CHANNEL SIGNALS	••	C		
FILTER PA	RAM	PARAMETEKS				
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	I		••	00100		
SAUKNO	•	NORMALIZED KADIAN FREDUENCY RANGE	••	00000.4		
NACI	•	NORMALIZED INITIAL RADIAN FREQUENCY	••	-2.00000		
L Z	•	NUMBER OF FREQUENCY SAMPLES	••	32		
LPBP	•	LOWPASS/BANDPASS UPTION	••			
		0 : LOWPASS 1 : BANDPASS				
CHANNEL PARAMETERS	ARA	METERS				
NCHNLS		NUMBER OF CHANNELS PER PORT	•	00		
180	•	CHANNEL SELECTOR AHRAY	•	1 0 0	0 0 0	0
			••	0 0 0 0	0 0 0	0
CHANNEL	1 1					
Z	•	AMPLITUDE OF WOISE SOURCE	••	1.00000		
IXO	•	INITIAL RANDU SETTING	•	-		
Z	•	FIRST-TIME-ON SAMPLE NUMBER	•	• ~		
æ	•	BLINK DURATION IN SAMPLES	••	10000		
I.	•	AZIMUTH ANGLES OF INCIDENCE (DEG)	••	45.00000		
CDEL	•	CHANNEL DELAY IN SAMPLE-TIME UNITS	••	00000		

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POEL	•	FRACTION OF MAXIMUM APERTURE DELAY	1 .00000	000
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RWOFF	•	BANDWIDTH OFFSET FACTOR	00000	000
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840FF	• 1	BANDWINTH OFFSET FACTOR		
WUEL	ì	PRACTION OF MANITOR AFRAICAE CELMI	•	

255 1.00000 .00000 .10000 NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY PORT NEL LOC1 RWFCTR BWOFF

V~169

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.51798	.07065	69669	.48862	.33408	.37157	72328	56526
48074	23750	28361	•13506	566	.10339	.17505	.00266
06351	11283	-,27575	25835	11409	.03865	.07953	.27617
00055	11477	.45163	.31794	25094	05660	53162	23005
.10719	05537	.29689	• 03985	22164	13245	32176	22894
37584	06600*	03879	• 09208	.23239	.18048	03938	.26500
60316	16595	22785	27799	.15061	•04556	.49787	.37387
• 05925	.20008	67018	26714	51800	17553	.41521	.42498
.46481	.55190	24892	960000	22334	22122	17884	20945
14507	08280	48178	- •33350	15841	23864	.03017	.12234
24554	.07161	.07142	.10982	.79057	.48893	.42141	. 42662
56044	25490	64559	51348	.04592	•16575	.45400	.33688
15341	20463	60188	43149	23294	.15095	05292	.03788
.70182	.26963	* 2999	.35405	.76554	.50367	.33146	.11205
.34201	.16069	22889	.04207	10227	.16877	.08978	.24863
.07344	10329	.46118	.36153	.51865	.34286	.17534	.33441
01579	•20465	.13439	.29129	17332	08765	.00878	.12494
21703	41773	.06459	23583	57301	59389	25661	38524
71106	39012	17869	31977	.16879	• 45005	15971	.15446
. 40747	.45486	.68229	.67181	.68674	.85576	08121	.25857
.30585	.30440	.19328	.26502	49591	22000	67983	41589
30495	53856	.35302	.05498	29988	.01301	08097	02180
.53397	.59253	08945	.13345	56349	37762	77427	36070
67043	15846	09813	.07619	07995	.11142	19310	00091
09846	05802	32365	11190	70209	51642	42425	15954
.35979	.29670	.55865	•31600	.34771	05137	.29572	17155
02046	.16899	40334	40163	33264	31392	.02263	.05234
29165	15834	.20012	.26848	.21792	.33672	.14525	• 09035
12944	•14092	11299	25	.11258	.27773	.18868	• 44658
*0827	.17843	.09463	.15595	23632	08516	.11600	-•09952

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73410	.11073	.10958	.73308	86029	01010	01218	-86120
99367	75509	76257	.99317	99R29	14661	7552A	1.0000

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03888	01323	.19071	.17610	66090.	.16573	.05320	07275
.02968	.0079	.07461	12495	.26860	17760	.18883	25049
11842	07928	48937	04960	.14693	.37919	66575	.31826
14744	27502	10648	.01617	.88963	26945	.09181	.11671
20862		23092	.15384	39795	22437	.61231	• 05531
.04496	09826	.08906	*6620**	77621	•44259	.26915	25769
1.00000	23204	54974	.16137	19118	.13871	41202	.07177
23740	08672	.76412	18493	26971	*04454	59677	.20878
.39803	.03190	.52495	19608	15468	12987	.12703	07027
60785	.39567	33618	15351	.12069	26231	26069*	37503
45617	.32986	.13514	• 06595	.31843	.00235	15037	04658
08588	.07293	00856	• 05025	.19804	18646	56763	.10918
02754	.00689	.61948	29271	.31554	12729	74146	* 4036 *
02025	.26382	16347	12197	.31903	39370	.64548	.03260
60283	.43451	57496	07616	00654	11513	.98510	26494
30998	11339	33380	.00750	.14768	• 03205	08365	.18227
38708	.05156	66419	.28229	.17821	30714	•66224	.11530
09250	10721	.10204	11146	03253	.06137	73031	.26788
.21265	16106	.18602	13511	12473	02217	.33990	04699
.62998	01110	36409	.03137	.00500	.15949	43009	09470
06632	.18151	.18172	40263	72752	.20569	.37521	14097
.15484	11836	.02065	12918	38379	.26239	.00183	.11941
.55595	24317	29769	.32131	31891	.13693	.45635	03862
.75436	31485	70351	•06789	52017	.21701	.37759	30430
07A77	01852	.01811	.33523	27060	12152	52439	-08092
.19224	25177	.60273	14255	44537	.09207	.46715	07034
20111	.04277	.10832	.11553	40186	.15682	.09062	36923
.79020	25614	.24858	.04701	.00931	.11621	92485	.05844
.42459	.09243	11328	.20698	07141	23948	.07394	.06588
37167	.03991	.17203	25067	.10553	.13580	.17998	05091
100		73700	70000	10110	00000	10000	97300

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.06001 .12031

-.09309 .13580

.10553 -.07141

> .00886 .07364

.22756

.14106 01564

-.35735 .34456

.03103

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(BB)

SUPPRESSION

V-172

	TA	AYLOR WEIGHTING	FOR	MAIN ANTENNA	A ARRAY		
40009	45003	50005	.50186	.50307	.50458	.50640	.50851
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64046	54577	.55105	.55661	.56244	.56853	.57489	.58150
C. 040.	04000	60285	.61046	.61830	.62637	.63467	.64319
65103	.66088	•67004	.67939	.68894	.69868	.70860	.71870
72897	.73941	. 75000	.76074	.77163	.78266	. 19382	.80511
81651	82802	.83964	.85136	.86317	.87506	.88702	90668.
.91115	.92330	.93550	.94773	00096	.97229	.98460	•
1.00024	1.02155	1.03385	1.04613	1.05838	•	1.08278	
1.10697	1.11897	_	1.14275	1.15451	1.16618	1.17774	1.18920
1.20055	1.21177	1.22287	1.23383	1.24465	4	1.26583	1.27618
1.28637	1.29638	1.30621	1.31585	1.32531	1.33456	1.34362	1.35246
1.36109	1.36950	1.37769	1.38565	1.39337	1.40086	1.40810	1.41509
1.42183	1.42832	1.43454	1.44051	1.44620	1.45162	1.45677	1.46164
1.46624	1.47054	1.47457	1.47830	1.48175	1.48490	1.48776	1.49032
1.49258	1.49454	1.49621	1.49757	1.49863	1.49939	1.49985	1.50000
1.49985	1.49939	1.49863	1.49757	1.49621	1.49454	1.49258	1.49032
1.48776	1.48490	1.48175	1.47830	1.47457	1.47054	1.46624	1.46164
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.70860	.69868	•6889•	.67939	•0019•	.66088	.65193	.64319
.63467	.62637	.61830	•61046	.60285	.59549	.58837	.58150
.57489	.55853	.56244	.55661	.55105	.54577	.54076	Ð
.53157	.52741	.52353	.51994	.51664	.51364	.51093	.50851
.50640	.50458	.50307	.50186	.50095	.50034	.50004	

	BASEBAND CHANNEL AMPLITUDE RESPONSE 1	MAIN-PORT BASEBAND CHANNEL AMPLITUDE RESPONSE 12 -26.35980 -26.52783 -24.70956 -22.88368 -21.04797 -19.30652 15 -14.87927 -13.88285 -13.13818 -12.61402 -12.23330 -11.88884 37 -11.07288 -10.89269 -10.80316 -10.89853 -11.19811 -11.72890 21 -14.25012 -15.21103 -16.18156 -17.13153 -18.03403 -18.89853	COMPOSITE BASEBAND CHANNEL AMPLITUDE RESPONSE 80 -32.03041 -31.42552 -30.83665 -30.28641 -29.71341 -29.37326 34 -29.68282 -30.61176 -32.03050 -34.27242 -37.79625 -42.71439 61 -38.01500 -34.38458 -32.18727 -30.56454 -29.54636 -28.97539 23 -28.97453 -29.37656 -29.73537 -30.14111 -30.61868 -31.08455	BASEBAND CHANNEL AMPLITUDE RESP.INSE 2	MAIN-PORT BASEBAND CHANNEL AMPLITUDE RESPONSE 69 -14.17362 -12.85739 -11.49469 -10.09601 -8.68230 -7.28719 63 -3.82824 -3.12086 -2.65897 -2.38732 -2.23139 -2.13645 48 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 -3.39295 91 -6.31034 -7.40009 -8.48114 -9.53406 -10.54722 -11.51543	COMPOSITE BASEBAND CHANNEL AMPLITUDE RESPONSE 56 -32.97908 -32.39885 -31.82541 -31.27599 -30.77669 -30.40169 46 -30.78613 -31.78796 -33.41043 -35.85718 -39.78143 -46.53316 25 -38.03241 -34.81860 -32.58838 -31.04456 -30.03014 -29.48505
www.c				BASEBAND	MAIN-PORT BASE -15.43969 -14.17362 - -4.79063 -3.82824 -1.97848 -1.91513 -5.24691 -6.31034	-33.55356 -32.97908 -30.29446 -30.78613 -43.43925 -38.03241 -20.29448

}	-
	FIELD PATTERN BEFORE AND AFTER BCR ADAPTATION ABOUT INTERFERENCE
	ABOUT
	ADAPTATION
	BCR
	AF TER
	ANO
	BEFORE
	PATTERN
))))	FIELD

MAIN FIELD PATTERN

44.87498	-22.91161	44.87889	-24.32169	44.88280	-26.02716	44.88670	-28.07201
44.89061	-30.58412	44.89452	-35-12675	44.89842	-43.23663	44.90233	-47.90111
44.90623	-37.76054	44.91014	-32.07393	44.91405	-28.60013	44.91795	-26.51216
44.92186	-24.73946	44.92577	-23.33789	44.92967	-22.00999	44.93358	-20.88618
44.93748	-19.96R09	44.94139	-19.09592	44.94530	-18.28661	44.94920	-17.57083
44.95311	-16.91776	44.95702	-16.31866	44.96092	-15.72820	44.96483	-15.22130
44.96873	-14.71785	44.97264	-14.34896	44.97655	-13.82789	44.98045	-13.37713
44.98436	-13.01956	44.98827	-12.62630	44.99217	-12.26140	44.99608	-11.94249
44.99998	_	45.00389	-11.44618	45.00780	-11.01364	45.01170	-10.73277
45.01561	Ψ.	45.01952	-	45.02342	-9.96329	45.02733	
45.03123		45.03514		45.03905	-9.06605	.45.04295	-8.86177
45.04686		45.05077		45.05467		45.05858	-8.09089
45.06248	Ĭ.	45.06639	-	45.07030	•	45.07420	-7.50201
45.07411	Ī	45.08202	Ť	45.08592	-7.07059	45.08983	-6.96996
45.09373	-6.84608	45.09764	-6.73148	45.10155	-6.61768	45.10545	-6.51336
45.10936	-6.40608	45.11327	-6.31509	45.11717	-6.21940	45.12108	-6.12637
		ì	14.190gm		į		
		3 i	CONTOUNIE FIELD FALLENA	CLU FAILE	.		
44.87498	-13.69902	44.87889	-13.93719	44.88280	-14.18113	44.88670	-14.45752
	-14.76876	44.89452	-14.99607	44.89842	-15.30442	44.90233	-15.61294
44.90623	-16.03488	44.91014	-16.31573	44.91405	-16.59506	44.91795	-17.00180
_	-17.41490	44.92577	-17.86496	44.92967	-18.28619	44.93358	-18.72659
44.93748	-19.26300	44.94139	-19.82639	44.94530	-20.36674	44.94920	-21.01154
	-21.68538	44.95702	-22.43054	44.96092	-23.21063	44.96483	-24.16283
	-25.14122	44.97264	-26.69908	44.97655	-27.66263	44.98045	-29.03015
44.98436	-31-18027	44.98827	-33.46918	44.99217	-36.64508	44.99608	-42.34927
_	-54.94867	45.00389	-38.65898	45.00780	-37.40787	45.01170	•
45.01561	-31.38101	45.01952	-29.09464	45.02342	-27.75264	45.02733	-
45.03123	-25.30199	45.03514	-24.28693	45.03905	-23.35655	45.04295	-22.53894
****			F-6.40	F		00000	

-20.04292 -17.89638 -16.31133 -15.01738

> 45.07420 45.08983 45.10545 45.12108

45.05858

-20.49840

-18.32764 -16.74706

45.07030 45.08592

-21.06075

45.06639 45.08202

-21.83128 -25.30199

45.04686 45.06248 45.07811

45.09373 45.10936

-17.44212 -15.96855 -14.74584

45.09764 45.11327

-17.01955 -15.63376 -14.45187

45.05467

45.03514 45.05077 -13.95106

-15.32909

-14.19274

45.10155

			MAIN FIELD	PATTERN			
	,	0000	ic	,	6.434 61	1	4000
•		20000	•	100000	300000	1 1000 4	•
•	•	0440	2400	7.87845	-0.38737	5006	95176
•	1	.9101	r.	90+16-6	.9965	9179	ø
•	7	.925	.5	9.92968	-21.75583	9.93359	-59.92409
•	•	•	-23.3	9.94531	7	9.94921	-15.47561
•	-	•		9.96093	ĭ	9.96484	-8.73459
•	•	•	-6.6	9.97656	ï	9.98046	-5.05833
9.98437	7	•	-3.7098	9.99218	ľ	60966.6	-2.56558
•		•	-1.5793	10.00781	-1.13508	10.01171	i
10.01562	•	•	• 03	10.02343		10.02734	•
10.03124	-	ö	1.3	10.03906	-	10.04296	
10.04687	ò	ö	2.3	10.05468	Ň	10.05859	8
10.06250	8	10.06640	3.15682	•	œ,	10.07421	
10.07812	m	0.0820	138	ö	3.9544	.0898	4.08673
10.09374	4.210	10.09765	4.32	10.10156		10.10546	4.53541
10.10937	4.62833	10.11328	4.7141	10.11718	4.79284	10.12109	4.86454
		Ö		FIELD PATTERN	Z		
	28364	878	49616	9.88281	72164	9.88671	95683
9.89062	•	9.89452	-1.46780	9.89843	•	.9023	9
9.90625	•	9.91015	-2.6696	9140	-3.01394	•	-3.37766
9.92187	-3.76444	9.92578	1.4.	9.92968	.6147	.9335	-5.07532
9.93749	•	9.94140	ŧ	9.94531	-6.68376	* 9492	7.3
9.95312	•	9.95703	-8.72	6.96093	-9.53418	5	0.4373
9.96875	-11.4	9.97265	-12.6051	9.97656	m	9.98046	-15.52864
9.98437	-17.4	9.98828	-19.9911	ċ	ň	60966.6	-29.7116
10.00000	9	10.00390	-53	0.0078	ě.	10.01171	7
10.01562	-17.	ċ	-15.4947		ė	10.02734	-12.6065
10.03124		0.0351	-10.47363	ċ		• 0459	-8.78813
10.04687	4	•	•	10.05468	-6.78979	• 058	-6.22598
10.06250	-5	•0664	•		•	.0742	•
10.07812	e .	.0820	-3.56553	10.08593	.2125	.0898	2.8794
10.09374	-2.5650	60•	-2.26845	10.10156	.9868	2	,
10.10937	-1.46932	10.11328	-1.23112	10.11718	-1.00533	10.12109	79169

	MAIN BEAM PATTERN BEFORE AND AFTER BCH ADAPTATION	
	IND AF	
	FORE A	
	RN BEI	
	PATTE	1
***************************************	BEAM	
	MAIN	•

	ı		MAIN FIELD	PATTERN			
12500	.3524	~	.40	11719	.4476	11328	29
10937	.5365	10	ŝ	10156	.6189	09766	.6578
09375	•	 08984	47.73094	- •08594	47.76514	08203	17971
07812	.8288	07422	.8584	07031	.8864	06641	.91.29
06250	.9378	05	96•	9450	.9831	S	.0035
04687	0224	_	.0397	03906	48.05554	03516	48.06985
03125	.08	2	.0939	02344	.1037	01953	.1119
01562	11.	0	48.12401	00781	.1277	-•003A	1300
.00000	• 13	.00391	.1300	18	• 12	.01172	• 12
01562	48.11876	.01953	.1119	.02344	48.10371	.02734	48.09395
.03125	•	0	.0698	0	• 05	.04297	.0397
.04687	• 02	.05078	48.00356	.05469	47.98318	.05859	.9612
0	.9378	w	.9129	.07031	•88	.07422	.8584
0	2A8	9	11	59	• 76	•0898	. 7309
.09375	9	• 09766	47.65788	.10156	47.61899	.10547	47.57854
093	N)	11328	47.49290	.11719	47.44769	.12109	47.40089
	·	00 1	COMPOSITE FI	FIELD PATTERN	zı		
-12500	47.35086	-12109	47,39839	11719	47.44431	11328	.4886
•	.5314	105	726	10156		160	•6502
09375	.686	0898	1	859	.7551	0850	.7870
07812	.81	0742	.8461	70	.873	1990	.8991
06250	O	05859	47.94614	0546	3	05078	47.98703
04687	00.	04297	.021	03906	.0370	3	.0507
03125	• 06	02734	48.07362	02344	•	_	•
01562	60.	01172	101.	078	.1046	39	.1063
00000	.1066	.00391	. 105	078	1026	_	•
.01562	48.09270	.01953	• 085	234	.0768	273	• 0666
.03125	•	.03516	.041	•03806	270	20	109
.04687	.9932	S	.974	546	.9533	92	.9312
• 06250	075	664	.882	703	.8556	4	.8273
.07812	• 7975	8	• 766	.08594	. 7334	868	1669.
93	.663	916	• 625	015	.5867	054	40
.10937	47.50415	.11328	47.46049	.11719	47.41525	0	4
					,		

The main and composite field amplitudes over a 0.25° sector about the incident angle of each interference are then plotted in dB. The numerical quantities below each individual snapshot gives the field amplitude in dB before and after adaptation. The data in these plots are produced by FIELD.

The last graph is also produced by FIELD. It is a plot of the main beam amplitude before and after adaptation.

3.0 COMPUTER SIMULATION RESULTS

The three structured programs, SIGGEN, BCRS and BCRP, described in the previous section provide the basis for investigating the BCR adaptive processing performance in a variety of interference environments and system configurations. The interference environment may consist of wideband continuous noise sources, periodic blinking sources with adjustable period, multipath sources or combinations thereof. The system configuration that may be accommodated includes an RF bandwidth capability of up to 10%, a Taylor-weighted main antenna array of up to 1001 omnidirectional elements, up to 20 omnidirectional auxiliary antenna elements nonuniformity emplaced over the main aperture, and up to 20 complex adaptive weights in single or multitap arrangements. The limit of 20 is due to the dimensionality in the programs, an intentional measure taken to keep the program requirement relatively small. If desired, this number may be increased by appropriately altering certain array dimensionalities as has been done when a case of 100 adaptive weights was exercised.

Presented below is a number of specific examples demonstrating detailed BCR adaptive performance under certain environmental and system conditions. General results derived from a larger set of examples are summarized next. This section concludes with some comments on BCR variations.

3.1 Specific Examples

Of the numerical examples included in this section, only the first is presented in exhaustive detail, both numerical and graphical. To economize on space, all subsequent examples are presented graphically conveying nearly as much information.

3.1.1 Blinking Source

Figure 3-1 gives the scenario and system description that involves one continuous and one blinking source, of equal peak power, incident upon a 255-element Taylor-weighted main linear antenna array in combination with four adaptively-weighted omnidirectional auxiliaries. The specific parameters indicated in Figure 3-1 were appropriately entered in the input data file, SIGGEN:D. Subsequently, the signal generation load module, SIGGEN:L, was executed, producing an output data file, SIGGEN:O, listed in Table 3-1 that follows.

Concatenating SIGGEN:0 to the BCR header data file, BCRS:D0, defines the input data file, BCRS:D, for the BCR simulation load module BCRS:L. The BCR simulation performance included in BCRS:0 is summarized in Figure 3-2. Shown here is the relative combined power suppression, $P_c(w)/P_0$, and relative gradient metric, $||r||^2/||b||^2$, as a function of iteration. To be noted here is the fact that the combined power suppression reaches its limit at the end of the third iteration. However, by choosing the stopping criterion $||r||^2/||b||^2 < 10^{-6}$, the BCR process goes through an additional iteration at which the relative gradient metric reduces below its threshold of -60 dB.

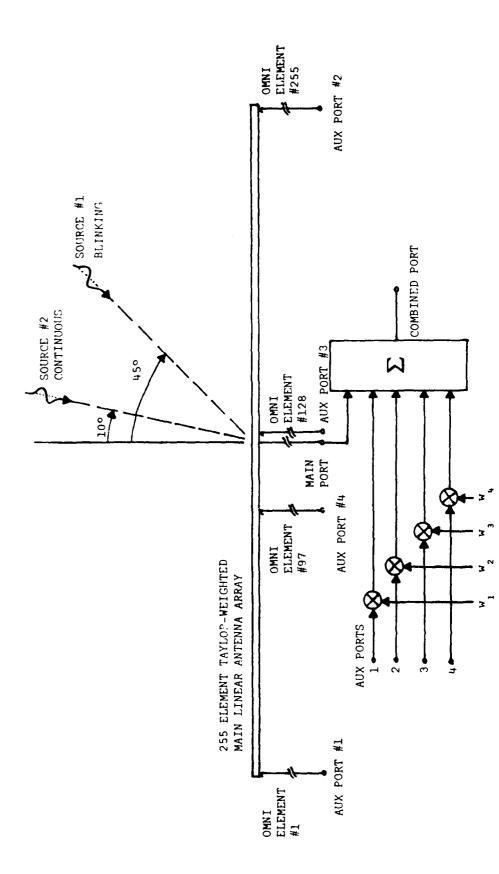


Figure 3-1. Scenario and System Description Blinking Source Example 0.1% RF Bandwidth

Table 3-1. Signal Generation Program Output File, SIGGEN:0 Blinking Source Example (See Figure 3-1)

	PARAMETERS	
*******	OF SYSTEM	
	SPECIFICATION OF SYSTEM	

PRINT OPTIONS	NO	PRINT OPTIONS			
1441	•	MAIN ANTENNA ARRAY WEIGHTING		0	
INGAP	•	RECEIVER AMPLITUDE AND PHASE	••	0	
I MM I	•	RECEIVER IMPULSE RESPONSE	•	•	
INCAP	•	CHANNEL AMPLITUDE AND PHASE	-	. 0	
INCI	•	CHANNEL IMPULSE RESPUNSE		. 0	
IMSC	•	INDIVIDUAL CHANNEL SIGNALS	•	c	
FILTER PARAMETERS	Ĭ	ETERS			
NPOL - NUMB	ļ	NUMBER OF LOWPASS PROTOTYPE POLFS	••	~	
		POL (1)	•	•	700
707	1		.		.10700
1001	1	FARCILLAND DANDEROLD AT UN	- •	00001	
91001	ı	TABLE CAMPONION AND AND AND AND AND AND AND AND AND AN		00100	
SANCE		NOTHELIZED MADIEN FREQUENCY RANGE	-	4.00000	
NOVE	ŧ	NORMALIZED INITIAL RADIAN FREGUENCY	••	-2.00000	
2		NUMBER OF FREDUENCY SAMPLES		32	
LPBP	•	LUMPASS/BANDPASS OPTION		~	
		d t LOWFASS 1 : RANDPASS			
CHANNEL PARAMETERS	MA	METERS			
NCKNI S IN NIKABE	į,	NIMBER OF CHANNEL A BED BODT	•	•	
	ı	CHANNEL SELECTED ADDAY	• •		•
CHANNEL					
Z	•	AMPLITUDE OF NOISE SOURCE	••	1.0000	
0×1		INITIAL RANDU SETTING	••	, pad	
7	•	FIRST-TIME-ON SAMPLE NUMBER	••		
₹ E	•	HLINK DURATION IN SAMPLES		10000	
I	•	AZIMUTH ANGLES OF INCIDENCE (DEG)	••	45.00000	
COFL		CHANNEL DELAY IN SAMPLE-TIME UNITS	••	00000	

1.00000 11 64 10.00000	1,00000 256 21 1 1 1 1 0 0 0 0 0 0	255 1 1.00000 .00000	1 1.00000 .00000 .00000	1 255 1.00000 .00000 .00000	1 2 8 1 2 8 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
00 M 00 N0 00 00	** ** ** **	*****		•••••	** ** ** **
AMPLITUDE OF NOISE SOURCE INITIAL RANDU SETTING FIRST-TIME-ON SAMPLE NUMBER BLINK DURATION IN SAMPLES AZIMUTH ANGLES OF INCINENCE (DEG) CHANNEL DELAY IN SAMPLE-TIME UNITS	AMETERS	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY	NUMBER OF ANTFNNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH OLFFANCE FACTON BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY
211111	AMET	511111	= 1 1 1 1 1	~ · · · · ·	# 1 1 1 1 1
CHANNEL AN 1X0 N1 NB TH CDFL	PORT PARAMETERS 100 1 AN NS NPORTS 1 NU 1 SP 1 PORTS	PORT NEL LOCI BWFCTR RWOFF	PORT NEL LOC1 RWFCTR BWOFF	PORT NEL LOCI RWFCTR PPOFF	PORT NEL LOCI BWFCTR BWOFF

1.00000 1.00000 .00000 NIMBER OF ANTFNNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLEPANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY PORT NEL LOC1 RWFCTR PDEL

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2 11 2

-.71622 .04238 .03776 -.00516 -,02532 .02608 .04063 .00812 -.12970 -,13046 .06554 .15388 .00465 -,14552 -.08110 -,63580 -.06053 -.37928 917 .02541 -.08377 -.01601 -.00494 -.09187 -.22471 .28417 12739 .15025 04026 .00971 1660 1.00000 -.00121 .03809 -.08910 -.08650 .23930 17537 -.70610 .49093 -,03339 .09941 .32677 .20487 .02428 -.02534 .04278 -.01376 .22813 .02165 .37230 .09918 .44110 -,12084 -.48443 -.65299 .39682 -.14106 .14884 -,05465 -,36462 .344914E **RECEIVED BASEBAND PORT SIGNAL** -.06901 .00527 -.06996 .02139 -.00815 .03213 .01979 .07513 -.06533 .62690 -.46263 -.189 9 •00996 .00954 .01648 .02078 .03839 .48333 -.53974 .14857 -.28668 -.52192 -.65158 -.29315 .19698 03341 -.15617 -.07621 .32195 .12822 .01098 00912 -.01674 NORMALIZATION CONSTANT .29592 -.01275 -.36700 .09405 .03382 .12022 -.09962 .13508 .11055 -.05850 .03104 .45015 . 32985 -.24025 -,36826 .30688 64660 .07050 .42029 -.09054 .14884 -.05144 .80607 .48275 .30418 .05332 -.16691 13201 .16201 14271 .22257 -.01136 .01380 -.04709 .01519 -,00393 .05173 .00358 -,03955 -.01043 -. 032AB .02656 -.04702 -,19906 -.11733 .04685 -.056A0 .02687 .11306 .06536 .16512 .33277 -, 10112 .51056 -,379A3 .19034 .05577 .04492 -.01004 .42961 -.14201 .638A1 -.09291 -.30987 -. US7A0 -.0431 -.07612 -.12442 .27782 .17723 .13446 -.01634 -.51290 .53824 .36947 18191 230 7 57038 27753 06675 -.40043 .17080 .17930 -,08983 .70079 -.07929 .18669 -.22620 -.07478 .05376 -,15603 .21394 -.46274 -,60615 -.26646 .2094B .37284 -.05785 -.20557 -.67290 .38237 .29137 .04276 .24740 13262 .00573 .61593 .01198 .04065 .01996 -,06523 .00753 .00052 -.00211 -,01661 -.02686 .05253 .07369 .07762 -,27415 .49376 -,08995 .33474 -. 02959 -,26371 .01560

07284

.22395 .07763 .07103 .04907 .01342 .24395

.00130

.15101

-.31855

-.14954

.26225 -.53182

-.03474

-.50218

-.0234A

-,23394

.21228 .05183 .10579 .47797

.04948

03297

.14242

.36659

.14148

The state of the state of

.12884	11030	32400	.10257	03406	01580	24069	.25159	12491	.02871	.01572	01844	.03416	75570	06014	02126	.27175	13432	.14726	73488	.29562	.41482	.19835	.18749	.39598	.31512	.29473	50495	.56253
.01083	02360	.00073	01083	06600*-	SEROO.	.01765	.05328	.02550	.05393	03746	.03879	05392	-,68303	.10274	.35906	.54954	29919	.08889	47699	.17787	.30049	.36797	.38586	.46880	.39107	.20714	51560	.35425
.01053	.07963	-,15392	.02000	-,12352	08386	-,19656	18670	20896	17186	.0304A	09491	.01614	97140	.32913	30247	25998	4109A	.59174	28557	12826	.11016	-,21187	.34279	.33073	0+61+	34344	.02295	.50261
.03242	02981	03292	.02498	.02566	.00399	00788	.06632	.02407	.01171	.02136	.00717	*07955	69023	.50302	356R9	03571	63714	.33201	15404	-,34242	.20660	06372	.39013	.2A159	.36457	36961	22947	.26749
00044	.23288	02858	09561	09401	13987	19856	25602	15976	04007	.09570	05579	17960	-,89993	.50644	+43974	13844	.04576	13848	.09520	33A32	-,21879	.14420	03502	03722	.11143	-,30195	03709	.59778
03807	03385	00096	.01453	01590	.02940	.01248	01261	03650	037R2	04911	-,00699	04315	73208	.38024	13491	16448	11482	-,37494	.06007	-,69652	-,05875	.16405	17839	.08341	.34860	54464	-,33393	.39826
18495	24960	-,13534	23959	.01175	-, 18941	10493	-16559	.24028	.02310	.26110	-,09923	16789	23619	12453	02372	.23795	.50681	.03964	04950	-,61200	-,15289	21406	.37959	36211	.23824	33590	.08410	03126
.00401	.01124	10000	.04371	.01767	01343	03166	.00507	.08166	.01298	.00275	.01396	.02385	-14536	.22940	.11849	.35205	,61324	. 29261	12184	47237	-,02565	.08415	10701	-13078	42048	30864	22027	.,11638

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	GCX.	RECEIVED NORMALIZATION	ED BASEBAND	PORT SIG	NAL 602822E 00		
00564	.01082	.07653	11958	.44603	57805	,51724	-,66812
.52697	69	20	64155	.49553	65320	,43521	56642
32384	•	08057	.11081	11566	11091	669	24315
18220	.24940	397	.50434	25236	.30659	.19213	-,23310
11509	-,14066	.14133	18590	21560	.29718	27458	,31315
11974		144	0	01613	.02783	22907	.28828
10711	15931	2680		•02406	04681	.03130	-,02691
-,34994	.45255	20951	.25009	02420	66650	-,32840	.43547
N	.34755	,12216		.05168	04811	10138	,12130
	.14445	-	W	28665	.37955	134	.40017
	31016	2072	*0652*	.09856	-,12637	99	-,14898
	03079	0571	08085	12575		-,09432	.13573
m	38656	1803	.22022	00601	.03379	10400	.12332
	.09641	0687	09719	25321	.36461	06257	.00520
	(C)	02079	02297	38	.56310	21179	.15122
.27312	2	.025A8	_	.04615	.07518	.06587	27987
.22553	.01996	-, 32561	.16076	51585	,46264	06020	.34176
17775	17731	.22684	.35627		.27024	09524	+010+
-,37645	.43263	08610	.39069	18893	-,01892	11509	.21152
.24137	ഹ	.41728	47881	04419	-, 73202	£6000°	48987
4	31018	08624	-,31369	24371	.59052	51441	.43175
00611	5850	13222	,-	.05454	1,00000	42620	.50173
-,00929	.42991	.09952	.25300	46141	09739	50248	29008
.13222	66059	.47451	16812	41045	13456	~.25887	.12420
.07288	99069	15525	.20909	3A601	-,31213	76341	-,16111
	.20534	27539	.23724	23974	.21471	-,30261	.14584
0	04225	28514	03296	41313	48610	61091	.07460
12853	. 35360	.54355	.17479	.64495	-,32099	.19177	.09261
-,17186	.27693	04345	48254	22417	-,27703	.00425	.03969
26103	09666	15403	.40830	00409	.41427	.07780	.09130
.06517	.14206	-, 32526	.21511	23468	.46381	28220	.64641
05945	.29140	06572	.18125	18357	.01176	.16443	-,20255
.14882	.50064	06361	.26617	.17510	21738	00981	.01779
-,39245	.47910	-,19566	.24343	.06876	174	03391	_
~	.12732	. 08290	11754	.45071	59125	.34907	41004

.20797	16086	54437	.17746	05823	03755	42117	.37060	23535	00900	.05943	04744	.09913	62178	28499	27010	.00249	.14592	.10189	80687	.30839	.36625	.04427	14795	.23426	.17164	.28446	364AB	.62714
15982	.12425	.42174	14378	.03644	.02816	.32601	28065	.18203	•00826	06865	.02573	-, 12033	40299	.37217	.57574	.59046	53524	,13116	.05943	.03420	.08654	,31414	.67267	,39454	.34509	.03305	322B4	04970
.00120	.16490	23712	.01080	22471	14897	-,33153	36397	-,36731	29095	.03985	-,17957	04545	93778	.05720	16385	-,35249	08338	.69917	37300	.21969	.03500	28942	.26759	.28166	.34282	09696	.22073	.58310
.01407	12643	.16960	00710	.18293	.10847	.24825	.29829	.29869	.23024	00624	16226	.09257	15958	.61641	248A7	.19698	69696	11891	.15654	63214	.16394	.15633	.25731	.11819	.16322	45356	36401	11306
.01349	.42194	05533	18246	14325	26019	34230	42610	22549	04112	.20674	08035	24793	85804	.48722	.54429	09452	10201.	.23168	.06562	*0690*	28755	.06411	.16432	07854	11686	05710	.31389	.60807
02013	-, 33329	.03575	13274	.10937	16602.	.27074	.31843	.17754	.01554	17655	.03720	.15805	18294	.11589	18626	10759	-,18214	70094	.04869	91073	.10673	.18822	35745	.07252	.45272	55540	67238	.03041
.29731	.41240	24901	44263	.03668	-,30695	-,15457	29215	.46065	.02362	.42818	-, 18293	.27896	-,31825	,12503	.16517	-,03433	.17481	.26685	-,15376	55966	-,26522	.29158	.43420	49710	-,04363	.19635	.28187	,18134
-,25287	-,31428	.20364	.35060	03068	.23054	.10664	.21998	3A777	02602	-,33377	.16451	20760	.14035	48810	38748	.47547	.64157	48672	.22093	22152	.22953	-,10547	-,14566	.20510	.58579	.25252	43721	-,39580

~	
POHI	

	SOZ	MECEIVED NORMALIZATION	D PASFBAND	PORT SIGNA	GNAL 715786E 00		
01179	.01666	12294	16594	36424	55664	-,39183	59137
16104-	100	3738	55	385	57573	-,31749	47694
-20870	-,32308	.11580	_	00324	.02630	-,10759	-,19656
19496	29196	· V	.45891	11354	.19085	14684	24484
07456	-,11116	09487	-,15107	.23485	.35126	054	.19432
05791	171	.02777	.05035	.04112	.05038	,15596	.25451
-15524	22737	-,13932	379	03684	03816	.03060	.02707
28373	44095	•	15526	.06935	.07633	.27878	.42423
14336	◂	09660-	-,16913	.00365	00590	92690.	.11478
- 09632	4	S	,23326	.24054	,35875	.21687	,33296
18829	•	*	.18573	09761	-,15497	06512	10939
02049	N	05968	08481	07651	-, 12655	.12475	.18051
21758		10319	.15840	.01768	.01547	.09290	.13440
01495	04030	01370	05010	.22032	.35018	-,06596	08328
-, 16632	27519	.05148	.06107	.33850	.53478	.00916	.03225
11773	20581	07214	-,11093	.04085	.07203	19789	29216
10016	10935	.05849	13250	.29448	.43840	13011	.21688
04577	12747	30095	.40822	.26786	.32953	.28599	.41610
26856	38959	.21166	.31975	02149	04066	.08562	.15507
42485	-,62800	•	37930	57629	77662	-,27545	-,39548
-,37236	42376	13945	23977	.38252	.60195	.22042	.34002
43792	59167	.62663	.83839	.71083	1.00000	.26454	.39310
31864	.41432	.15288	.22303	15054	16971	-,34813	42371
45322	-,66918	.01949	01090	.01027	.08949	.09765	.12189
50951	71817	.04375	.09621	27826	-,37236	21671	22757
-,00163	.09275	06060	.15427	12326	11961.	.01608	.05464
02835	-,04356	12600	-,12124	40406	53647	.00100	.05227
24930	•	.17263	.19925	11841	24821	.18749	.23317
09454	.18701	-,37423	53072	-,18394	25327	.00304	.03106
•	-,10537	.30764	.43305	.24598	.36363	.08481	.08749
12188	.16501	.12168	.19449	.32354	.46231	.39678	.58887
16636	.22718	.13063	.17889	07349	07296	06405	-,14353
.41220	.57836	.11400	,18496	12120	21310	•	.08640
28745	45174	,08696		37	190	.05425	•0400
.06229	.10373	-,11852	16522	37430	57429	14783	-,25527

.20833	21681.		CF051.	05472	01755	36245	. +2941	-,17582	.07803	.02047	.02762	.05693	60140	20964	19321	.12477	.10200	.02686	81481	.25629	.41349	.17614	-, 12149	.26283	.19631	.30433	42453	.61260
13871	-,16341	00636	10060	04690	01461	23673	.28056	-,11537	.06082	.00425	.03146	.02015	46790	12027	07463	.13839	.04784	.02484	57966	.17444	.29201	.16301	-,05193	.21855	.17248	*1212 *	-,31341	.44616
.03387	50101.	*****	. 04463	17914	-,12302	-,30751	25248	31784	26060	.04215	17874	.02474	94446-	.07564	27568	-,33078	18869	.65338	41419	.12482	.09861	-,29313	.26619	,31146	.39676	-,14153	.08595	.57566
.03525	00000	200/1-	11860.	10993	08484	21033	15019	20091	16177	.03982	12002	.02811	68789	.10132	20650	20902	17909	.45073	29396	•05594	.08621	19101	.21484	.22159	.28604	10907	.02201	.41123
04105	00000	20000	-13640	15791	20147	30467	40207	27891	07936	.12686	05851	27047	92126	.46476	.47432	13076	.09554	.17110	.06062	00603	23291	.05130	.10335	.00016	•00276	15872	.22947	.60865
03061	*2122*	00000	01440.	10483	12869	19580	27055	-,17522	06276	.07918	04117	17126	67817	.32622	.30034	11044	.04708	*********	.03112	0904A	15050	.05039	.06523	.01198	.05195	16071	.12957	.42691
30390	39510	11961.	. 34990	.00641	30113	17912	25067	.33465	.05447	.40258	17303	.22001	36464	.13406	.21420	.07489	.28073	17196	+0460*-	49710	-,29245	.24766	.41666	43869	.00170	.25089	.22648	.20655
.17866	.26210	0.16036	-, 62386	.00355	19873	-, 12633	17276	19621	.03107	.25362	-, 10843	.12367	26219	04440	.14289	.06917	.23118	.07001	02988	36822	-,18997	.17279	.26176	29029	.04182	19203	.12200	13590

.15846 .42175 -.23728 -.25886 .27052 .29210 .45885 .39047 -.55483 -.00045 .12666 .17018 .13968 -.04037 .27628 -.43798 .14353 .05769 -.13784 -.29433 19227 .42513 -,32204 -.13270 .12073 .11567 -.18674 11201. .48072 .08253 .64122 .07475 -.02982 00225 .01885 .02466 .01946 -.01770 -.01575 -.00813 -.02614 -.06046 .07843 .00993 -,15996 -.34725 .12566 .00858 -.00961 -.01716 .01175 -.00070 -.04863 .07565 -.09386 -.03668 -.06116 -.09610 -.26188 .00716 .07802 .07892 .02817 .000040 .03210 -,43381 0 -,65466 .07339 .04086 .07072 -,15270 .02355 .38175 -,75580 -.60738 .26457 .34950 -.02834 .39409 -.15149 .07015 .49607 .27034 -.01534 .14768 .31235 ,22571 .38702 -,23142 .58387 .62127 .00000 -.09617 -.48135 -.33797 .48373 -,01955 .04371 -.24444 -.62408 .756774E RECEIVED BASEBAND PORT SIGNAL 84610. -.00709 01210 .02375 -.02070 -.01983 -.00714 .00342 .01203 .00870 .01102 .00785 .00965 .21039 .01015 .27866 -.28153 .05965 -.17220 -.05175 -.37085 -,19353 .12876 .04920 .02038 -.00577 -.00257 .04447 -.07821 -.09211 .35555 -.26331 -.29423 **-.08974** .02289 PORT NORMAL IZATION CONSTANT -.63703 -.15227 .21439 .25762 .23706 .20148 .16040 .43649 .15861 .51502 -. 18116 .05757 .29553 -.17185 -.06821 -.07814 .02614 -,13171 .17432 .36754 .35931 -.45861 -.26933 .80784 .22837 -.12240 .21120 -.05682 .14246 -.50797 .23309 .18737 .22750 .15159 -.004A3 .01872 .007A6 -.00490 .02617 -,00796 -.01572 -.020AB .31985 .07579 -.00506 -.02436 -.01630 .01409 -.01442 .00012 .00579 -.03814 -. 12022 .23338 .08193 .03673 -.12040 .34445 .11755 .16839 -,18922 .02855 .05117 -.00063 -.05041 -,16237 -.08417 -.01191 -.01421 -,31924 .22379 .33258 -.69426 58990 26009 -.39470 -,13316 -,13422 .47983 .31323 .15239 .31075 -.027R2 07043 .05078 -,16635 -.63125 -.20931 .44271 -,33092 .42253 -.68277 .07933 .15019 .39061 53414 ,12429 .29121 .03651 50040 .06048 .00055 -.02088 -.00345 -.00573 .04368 .01675 -.00672 .00647 .01934 -.00304 -.02089 -.00160 .12173 -.02399 -.073A3 -,37012 .20496 .15960 -,14390 -.38606 -.05402 -19122 .00035 -.16150 .02101 -.02421 .04091 .26617 .07434 .07273 .23772 -.03025 -.01078

.22227	56161	.17920	05836	02795	41806	.43128	21873	.04617	.04413	00706	.08672	57813	27440	-,28065	.01908	.16688	.04765	81859	.27606	.38742	.09071	-,19254	.21639	.15479	.29158	-,37306	.62513
00761	.02287	01144	00490	*E000°	.01684	01532	.00845	.00602	01416	00144	02716	41695	.07294	.21118	.30239	20098	.09140	25076	.11657	.15859	.17942	.26607	.27896	.23495	.10814	28464	.19560
.01908	26314	.03337	21600	14458	34018	-,32904	36616	29568	.04181	-,19503	01287	93169	.01335	20527	-,35972	08147	.68466	41097	.21887	•05524	30639	.24432	.28884	.36220	08436	.17654	.59138
.00886	.00186	00026	.01441	.00181	.00711	.02428	.02198	•01653	.01202	.01747	.02815	39444	.32343	17581	01273	36986	.18208	05501	-,21834	.10057	01915	.22943	.15229	.19458	-,23396	11033	.14294
01731	04919	16648	16156	24536	34566	44206	27320	06419	.17673	07025	27731	87874	60494.	.52236	-,10374	.11875	,25834	.06028	.10782	26579	.04113	.16170	04086	08876	06376	.32616	.60482
00336	00381	16000	.0052B	.01373	.01708	.01091	.01484	00698	01432	00929	00160	39107	.22167	.08246	-,08655	06729	24862	.03905	-,43436	04226	.11248	10814	.01923	16691.	30348	21345	.21906
.32632	23744	41989	*02224	-, 32585	-,17842	28772	.42526	.04436	.44531	-, 19339	.26607	-,35753	.17143	.22910	01287	.17925	.25539	-,13948	50734	30235	.27737	. 44012	-,48162	06871	.20772	.29057	.23019
02868	.01638	.02042	00180	01005	00074	.00597	03590	00646	02171	61913	01230	04847	-,18235	11940	.20263		16495	.06544	-,30012	.01889	.05201		06978	.26871	.17895	-,13212	11551

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.27479 -. 75109 -.62486 -.26673 .31358 .14171 -.00747 .50710 -.15706 .18162 .15697 -.30340 .43292 .20768 .51819 .56259 .20689 -.04580 .17018 .68736 -,19553 .05399 .32617 -,02522 -.44664 .25994 .20844 .13824 .01314 .09012 07747 43997 .41310 -.28261 .14011 -.13342 -,11713 .22220 .09756 .01209 -.04743 .17425 -,22952 -.06386 .00871 -.14776 .01577 -.01185 -.23272 .36285 ,03508 .24466 -.33099 16460. -.04657 -.02984 -,13794 .45861 .51955 .03650 -,15516 -,04533 .07800 -, 10921 -.09611 .14116 -.67253 .22700 .06026 .09143 .30749 .37793 .04226 .07708 .43783 -,16392 -.17077 .02605 .41592 .63512 .59527 .02073 -. 77314 .62563 1.00000 -.25859 .24808 -.44245 -.05031 -.03664 -.03301 .18727 -.20690 .38072 .52607 .24315 -.6A843 -.41801 .00591 .649192E RECEIVED BASEBAND PORT SIGNAL -.75121 .19997 -,10309 -.09608 -.04923 -,10376 -.00694 .00453 -.00515 .05568 -.14717 -.08464 .58975 .02057 -- 12494 .05065 -.09902 -.23703 -.38947 13287 .54214 -.31085 .09323 .45208 •00939 -.08154 -.30352 -.21795 .07635 .08608 .04237 .32061 .20731 NORMALIZATION CONSTANT -.16214 .16494 .57382 -.20458 .06394 -.33546 .24935 .28658 .09698 .36615 -.52960 -.23969 .81610 -.21210 .17182 .24355 -.51355 .47540 -.18536 .02807 -.13487 -.03114 .06846 .34534 .27141 .23251 -.08611 19761 .20127 23751 23551 .20001 .1625 .03535 -.39097 -.06731 .06109 -.02170 .06358 -.0673B -.23131 111790 -. 08285 -.08680 .0247B .10559 -,23842 .15029 .28138 -,10465 .16182 -.40050 -.17607 .05747 .03690 .05152 -,63967 -.21801 .400A2 00873 -.17620 -.04701 -.08451 -.07954 -.08391 .03773 .17437 -.14821 -.22151 -.53028 -.03223 -.27632 .31521 .45739 31950 .13658 -.66589 -. 77788 -. 44R69 .16867 -,36504 -,15094 .35963 .34834 .60836 -.69857 .69238 .35146 04905 55949 .07911 -.29684 02884 14198 -,13177 -.08753 -.15973 -.09598 -,30489 .41585 -,34546 -.44879 -.00296 .22414 .13482 .04724 .06085 .05585 -.12174 -,04732 .00464 -,13800 -.05023 .04584 -, 12436 .45989 -,41300 -,54235 .31680 .09237 -,15186 .21549 -.12405 -.17470 -.15748 .07177 -.04589 .09401

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.24505	-,62448	.20011	-,06558	03387	46926	.46690	24973	.04175	.05687	01159	10496	55940	-,33892	-,33894	04792	.24748	.02632	84473	.26352	.36835	.05753	29973	.17797	.12390	.27237	34237	.65493
07175	.18680	06484	.01130	.00862	.14017	13637	.07420	00121	01667	.03577	03301	.66411	.05169	09318	31302	.16815	12961	.57267	24028	-,31184	18717	22295	38175	-,31043	22022	.46492	43023
.01863	28814	.03127	-,24410	16347	37905	-,37771	41002	32894	.04483	22222	02984	92879	06097	16454	-,37840	.01492	.70876	84044-	.31791	.0401A	-,32377	.23050	.27257	.34840	00039	.21827	69619*
.01130	.07541	00808	.07986	.04388	.10556	.12605	.13170	.10692	00558	.04213	.00210	.76353	35046	.25775	.15784	.41817	46432	.18819	.14472	12429	.13824	33727	28310	35186	.29837	99020.	35766
01337 46052	05703	19126	17605	27857	38412	49134	29290	06585	.20713	07468	29641	87504	.44676	.53684	08246	13915	.37409	.04973	.20758	27763	.01856	.23210	04034	13660	.00397	.43477	.59574
00788	.01036	.05023	.05117	.08835	,11934	.13826	.09162	64800.	06570	.03804	.10903	. 73382	43607	-,32509	.10071	.02283	.19729	08634	.39639	.16572	-,13464	.06081	66400.	13415	.32903	.11364	47310
.35874	26854	47637	.02881	36021	-,19385	-,32370	.48510	.04532	.49196	21893	.29483	-, 39152	.24419	.30714	-,10322	.07760	.29319	-,15519	49822	33881	.30857	.44423	-,50965	14536	.16564	,33571	.30185
-,12048	.08866	.14700	00983	10344-	.04817	.0903	16798	01369	-,15865	- 94950.	12377	.16496	.12958	.06617	20494	45441	.06260	.02140	.53209	.09280	17034	-,254A0	.27436	26052	25391	.02872	.06367

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.le BCRS:0				•			· C			256		20	1 1 1 1 1 0 0 0 0 0	1 000000000	
Table 3-2. BCR Simulation Program Output File BCRS:0 Blinking Source Example (See Figure 3-1)	DIGITAL ADAPTIVE ARRAY PROCESSING	USING	BATCH COVARIANCE RELAXATION		5	OPTIONAL OUTPUT OF SO		OPTIONAL DUTPUT OF C AND B	Sœ	MAXIMUM NUMBER OF SIGNAL SAMPLES	INITIAL WEIGHT-VALUE OPTION	MAXIMUM NUMBER OF WEIGHTS	WEIGHT SELECTOR ARRAY	MAXIMUM NUMBER OF ITERATIONS	ITER - ACTUAL NUMBER OF ITERATIONS
) 					NOI			•	ETER	•	•	•	•	•	
					PRINT OPTIONS	IWSO	INNI	INCB	ACR PARAMETERS	NSX	071	X	I SH	ITERX	ITER

SPECIFICATION OF SYSTEM PARAMETERS

PRINT OPTIONS					
INANT INANT INANT INCAP- INSC		MAIN ANTENNA ARRAY WEIGHTING RECEIVER AMPLITUDE AND PHASE RECEIVER IMPULSE RESPONSE CHANNEL AMPLITUDE AND PHASE CHANNEL IMPULSE RESPONSE INDIVIDUAL CHANNEL SIGNALS			
FILTER PAR NPOL FBIF FBRF RADIN NF LPRP LPRP LPRP NCHNLS ISC	E V	RAMETERS NUMBER OF LOWPASS PROTOTYPE POLES POL(1) POL(2) FRACTIONAL BANDWIDTH AT FINAL IF FRACTIONAL BANDWIDTH AT RF NORMALIZED RADIAN FREQUENCY RANGE NORMALIZED INITIAL RADIAN FREQUENCY NUMBER OF FREQUENCY SAMPLES LOWPASS/BANDPASS UPTION 0 1 LOWPASS 1 1 RANDPASS 1 1 RANDPASS 1 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 COMPASS 1 CO	*********	70700 70700 10000 -2.00000 -2.00000	007
EL 1		AMPLITUDE OF NOISE COURCE	••	0	
C IN		SETTI SAMPL	99 99 I	1.00000	r.
TH COFL	. 40	711	10 (* 00 Gg	10000	

1.00000 11 64 64 10.00000	1.00000 256 21 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0	255 1 00000 • 00000 • 00000	1.00000 .00000 .00000	255 1.00000 .00000.	1.00000 .00000 .00000
				•• •• •• ••	00 00 00 00 No
AMPLITUDE OF NOISE SOURCE INITIAL RANDU SETTING FIRST-TIME-ON SAMPLE NUMBER BLINK DURATION IN SAMPLES AZIMUTH ANGLES OF INCIDENCE (DEG) CHANNEL DELAY IN SAMPLE-TIME UNITS	 ANTENNA-ELEMENT SEPARATION FACTOR NUMBER OF SIGNAL SAMPLES NUMBER OF PORTS PORT SELECTOR ARRAY	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLFRANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLFRANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLFRANCE FACTUR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY	NUMBER OF ANTENNA ELEMENTS LOCATION OF THE FIRST ELEMENT BANDWIDTH TOLERANCE FACTOR BANDWIDTH OFFSET FACTOR FRACTION OF MAXIMUM APERTURE DELAY
~ 1 1 1 1 1 1	PARMETERS I I I I I I I I I I I I I I I I I I I	511111	= 1 1 1 1 1	~ · · · · · ·	m 1 1 1 1 1
CHANNEL AN 1 X 0 N 1 N B TH CDEL	PORT PARAMETERS 100 100 100 100 100 100 100 1	PORT NEL LOC1 BWFCTR RWOFF	PORT NEL LOC1 AWFCTR RWOFF	PORT NEL LOCI BWFCTR RWOFF	PORT NEL LOCI BUFCTR 9WOFF

1.00000 1.00000 .00000 NUMBER OF ANTENNA ELEMENTS
LOCATION OF THE FIRST ELEMENT
BANDWINTH TOLERANCE FACTOR
BANDWINTH OFFSET FACTOR
FRACTION OF MAXIMUM APERTURE DELAY PORT NEL LOC1 BWOFF PDEL

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1	! !		-	1614954	10151. 77		•	82 ,26613	•	•	·	•	12 .07103	10640 18	•	4624395	•	•	14188	7145208	52 .14242		8053182	•	•	i	i			•	•	1713408	26 .03297	•	17 - 10676
0	.015	.02541	.03776	00516	08377	01601	.04238	.0168	00494	02532	.02608	.04063	.0081	•		-,13046	.06554	.15388	.00465	22471	14552	08110	63580	06053	71622	182	-,37928	.28417	.00971	.12739	.1502	.06917	•	.0195	1000
SIGNAL .344914E 00	-,35142	37752	.03809	.14884	.20487	.02428	02534	.04278	01376	.22813	08910	08650	.02165	.23930	.37230	.09918	.17537	.44110	12084	70610	64064	1.00000	-,30750	-,03339	48443	.09941	65299	00121	-,38017	.39682	.32677	08525	14106	-,05465	- 36462
PORT SI	01194	96600.	96690*-	06901	.05337	.02139	00815	.03213	.03341	* 0095 *	01979	.01648	.00527	.02078	.03839	.07513	06533	.48333	15617	53974	.14857	.62690	46263	28668	52192	07621	65158	.32195	-,29315	.19698	.12822	18969	.01098	.00912	47410 -
HECELVED BASEBAND IZATION CONSTANT	+9060*-	36700	.09405	.29592	10447	.03382	16491	.12022	09962	.14884	.13508	05144	•11055	05850	01275	12781	*0310	.45015	.32985	24025	-,36826	.80607	.30688	6 9 6 6 0 .	.13201	.07050	16201	.42029	48275	.30418	.05332	.14271	.22257	12229	04440
MECEIVEL NORMALIZATION	04709	.01519	.046A5	01136	.01380	00393	.05173	05680	01004	.00358	03955	01043	032AR	.02656	.02687	04702	15906	.42961	.11306	.06536	14201	.638A1	.16512	.33277	10112	09291	30987	.51056	37983	.19034	-,11733	.05577	.04482	057A0	04312
ĬĊ.	.00A59	40043	22620	_	07478	07612	12442	.27782	.17723	.08830	.17930	01634	.22515	.05376	-,15603	08983	13446	10419	.21394	46274	-,51290	.53824	.36947	60615	.70079	26686	07929	.37284	.18669	20948	18191	.23067	.57038	.27753	04675
	.00573	.01198	.04065	.04276	.01320	.01996	05785	.00947	06523	.00753	.00052	-,00211	01661	-,02686	,05253	.07369	.24740	.07762	-,00762	20557	67290	,38237	.29137	27415	.49376	-,61593	-,08995	33474	••02959	-,26371	.13262	.09767	.46172	00780	01560

01572 -.02126 -.13432 -.13488 -.73488 -.73488 -.73488 -.19835 -.32400 -.03406 -.01580 -.24069 .12491 31512 29473 .25159 .03416 ..75570 -.06014 39598 50405 .56253 .01083 -02360 -00073 -.00990 .00835 .01765 -,05392 .10274 .35906 .54954 .29919 05328 02550 05393 05393 36797 46880 39107 20714 51560 35425 38586 -.47699 117787 -.12826 -.21187 -.21187 -.33073 ..25998 -34344 02295 50261 .01053 .07963 .15392 .02000 .12352 -.19656 -.18670 -.20896 -.17186 .09491 .01614 .97140 .32913 .59174 -,28557 -.35689 -.03571 -.63714 -.15404 -.34242 -.20660 -.06372 -.39013 -.28159 .03242 .02981 .03292 .02566 .0399 .06632 .02407 .01171 .02136 .00717 .07955 -.22947 .33201 36961 .09570 -.05579 -.17960 -.13844 -.13848 -.13848 -.33832 -.21879 -.03502 -.03722 -.11143 .23288 -.09401 -.13987 -.19856 -.25602 -.15976 .50644 19560 -.30195 -.03709 .59778 -.0940 -.02940 .01248 -.01261 -.03650 -,00699 -,04315 -,73208 -,38024 -.69652 -.05875 -.16405 .18341 .34860 -.54464 -.33393 -.03807 -.03385 -.00096 .01453 .13491 -,11482 -.16448 .06007 -,17839 -.04911 -,37494 .21406 .37959 .36211 .23824 .33590 .08410 .18495 .24960 -.13534 -.23959 -.18941 -.10493 -.16559 -.61200 .03964 -.04950 .01396 .02385 .14536 .22940 .35205 -,01343 -.13078 .30864 .01124 ,61324 .12184 -.08166 -,00275 -. 47237 -,02565 .08415 .10707 -.11638 -.01767 .01298 .00500 -,29261

C •192330£ 02	35086 .52788 .03722 35615 .39603 .82937 00000 .58368 .47575 47575 .98933 .00000	•786043E 01	.03217 .2683566954
MATRIX	55829 .8293200000 .86348 .982937 .58368 -	FORCING VECTOR R	.15244 1.0000003217
LOVAKIANCE NORMALIZATION CONSTANT	.00000 .50481 .55829 1.00000 .35086 .86348 03722 .39603	NORMAL IZATION	.6759820474 .93374 .15244 1.
	.93493 .50481 .82932 .52788		.87598

			TOWN CAMPACE			NOT LETOLIC			
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	•								•
V	••	.93493	00000	.50481	55829	.82932	-,35086	.52788	.03722
	••	.50481	.55829	1.00000	00000.	.86348	.35615	.39603	.62937
	••	.82932	.35086	.86348	-,35615	.98264	00000	.58368	.47575
	••	.52788	03722	.39603	82937	.58368	-,47575	. 98933	• • • • • •
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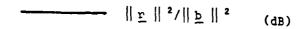
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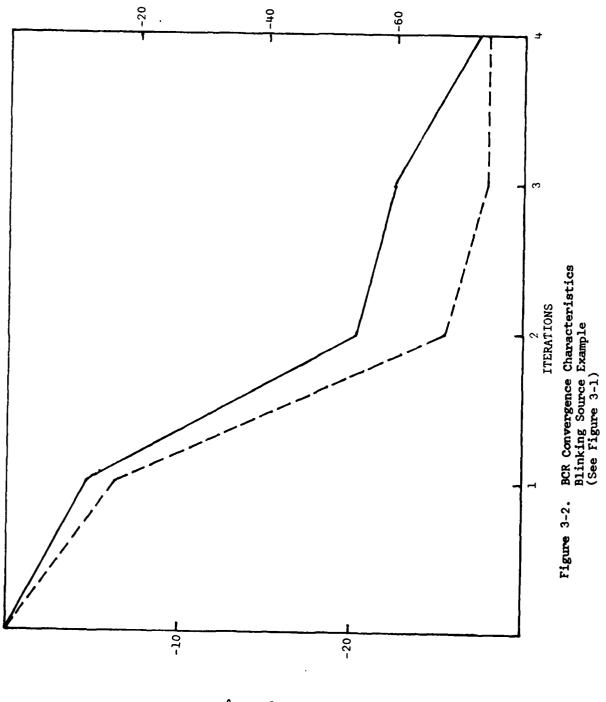
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The input data file, BCRP:D, for the BCR plotting load module, BCRP:L, is constructed by modifying BCRS:O. The actual number of BCR iterations is entered in the location marked with an X in the BCRS:DO header. Subsequently, the output between the end of the "PORT O" listing and the beginning of the "COMPOSITE WEIGHT-VECTOR ARRAY" listing is deleted. The resulting input data file, BCRP:D, is used to execute load module BCRP:L yielding an output file BCRP:O containing numerical performance information accompanied by a corresponding graphical representation. Output file BCRP:O is listed in Table 3-3 and is immediately followed by the graphical output in Figure 3-3, which is self-explanatory.

The present example serves to demonstrate the nulling capability of the BCR process in a dynamic interference environment. Although a dynamic algorithm would tend to exhibit a transient behavior in the presence of a blinking source, the BCR process is essentially immune to this undesired phenomenon, as evidenced in the controlled signal amplitude of Figure 3-3(b).

Figure 3-3(c) describes the evolution of the BCR-adapted weight-vector components in the complex plane in four iterations, beginning with an initial estimate of $\underline{0}$. Because the fourth iteration accounts for a relatively infinitesimal change in weight-vector value, only three distinct breaks may be observed in the weight-component loci.

Figure 3-3(d) gives the baseband channel amplitude response for each of the two sources before and after BCR adaptation. Note that, even for the rather low RF bandwidth of 0.1% in this case, the source transfer functions through the main antenna exhibit a non-symmetric amplitude response, a phenomenon which will be more pronounced with increased bandwidth. The adopted channel amplitude responses shown exhibit a stopband behavior within the capability of the four degrees of freedom provided via the four-component adaptive weight vector.

Figure 3-3(e) depicts the field pattern amplitudes, before and after BCR adaptation, over a 0.25° window about each of source angles of arrival, evaluated at the center RF frequency. Since the sources are concentrated at specific angles of arrival, the adapted patterns exhibit sharply defined nulls. Note that, in contrast, the adapted channel amplitude responses in Figure 3-3(d) simply describe the frequency dependence of the adapted pattern nulls over twice the 0.1% RF bandwidth referred to normalized baseband.

Finally, Figure 3-3(f) shows the effect of adaptation to the main bean. Clearly, the adapted main beam differs almost imperceptibly from the original main beam. This desired behavior is essentially due to the fact that the auxiliary antenna gains determined by the adaptive weights were necessarily low so as to match the main antenna sidelobe gains at the two angles of arrival.

3.1.2 Source-Strength Variation

The next two examples address the BCR nulling performance with equal and unequal source strengths. The latter case is of particular interest since it can give rise to an ill-conditioned covariance matrix.

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.25159 .31512 .12884 .29473 -,50495 -.24069 .02871 .03416 -,13432 .14726 .29562 .41482 18749 .39598 .56253 .01572 -.75570 -.02126 .27175 .73488 19835 -,32400 10257 -.01580 -,01844 -.06014 -,03406 .01083 03879 .29919 -.03746 -.68303 .08889 -.01083 .00835 .02550 .35906 .54954 .47699 17771. .30049 .38586 .46880 .39107 51560 .35455 .00073 06600 --.01765 .0532b .05393 .10274 .20714 .36797 .34279 .02295 .01053 .03048 .59174 .11016 .33073 .41940 -,12352 -.08386 -,19656 -.18670 -.20896 -,17186 -.97140 .32913 -.30247 -.25998 -.41098 -.12826 -.21187 -,15392 .02000 -.09491 .01614 -,28557 -.34344 .02566 .39013 .26749 .50302 -.34242 .20660 .28159 -,03292 .02498 .00399 -.00788 .06632 .02407 .02136 .00717 .07955 -.69023 -.35689 -.03571 -.63714 -.15404 -.06372 .36457 -.22947 -.02981 .01171 .33201 -.36961 -.89993 .09520 -.33832 -.21879 .50644 .11143 -.03709 .23288 -.02858 -.19856 -.25602 -.15976 -.04007 .09570 -.05579 -.17960 .04576 -,13848 .14420 -.03502 -.03722 -.30195 .59778 -,13987 -.13844 -.09561 -.09401 -.01261 -.73208 -.11482 .01248 -.00699 -.04315 -.16448 .06007 -.05875 .16405 -.17839 .34860 -.54464 -,33393 ,39826 -,00096 -.01590 .02940 -.03782 -.69652 -.03385 .01453 .08341 -.03807 -.04911 13491 -,16559 -.12453 -.13534 -.23959 .01175 -, 18941 -.09923 .23795 .18495 -.23619 -,15289 ,37959 ,33590 -.04950 .21406 .23824 .0A410 .03126 .26110 -.61200 -,36211 .02310 .03964 .01298 -.02565 -.13078 .42048 -.11638 -.02385 -.22940 -.11849 -.47237 .08415 -.01767 -.00275 .61324 .12184 .10707 -,01343 -,03166 .00500 -.08166 -01396 -,14536 .35205 -,29261 .30A64 .03007 -,22027

		.00000 .32132 .52246 .30872
	NO.	.0000 .12878 .64541 .32786
4 A Y	ACR ITEMAT	.00000 .01544 .20327 -11785
COMPOSITE WEIGHT-VECTOR ARRAY	(NOICATED RCR ITEMAT	.00000 47991 68239 60881
TE WEIGHT-	ECTOR AT I	.00000 .07316 .20066 .63192
COMPOSI	ADAPTIVE WEIGHT VECTOR AT INDICATED RCR ITERATION NORMALIZATION CONSTANT : 267978F 00	00000 00000 00000 00000 00000 00000 0000
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PORT
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;	NOR	RECEIVED	ED RASEBAND N CONSTANT	PORT SI	5408		
01670	01049	.14383	10235	.14944	11248	.06150	11227
.07382	1051	0399	0	.06327	9	.00489	0
04627	005	18414	•05696	.15259	06112	02997	.03696
-,17560	0774		•06596	.13334	05205	.07868	02439
-,03603	0	.00239	.02126	23412	.08834	.15389	04995
00440	02	00968	01289	04717	.05324	0	00255
.20711	0	08196	.01541	.01355	02213	69660*-	.07687
-,13751	.06353	.12372	00784	06997	.06417	-,12808	.07315
11987	02488	.08726	01470	08657	.02446	01831	.02120
04195	0	05173	.05323	090A4	.07811	.01416	.03828
-,03394	.05041	.06279	02406	.10788	03024	03759	.00075
000AS	01482	.03556	02295	00774	.01613	-,14218	.07335
03194	.04391	.07460	01148	0027A	.04103	03552	00372
.05876	.01367	03805	.01610	13111	.07019	.22880	-,11424
02414	.04605	-,12771	.02026	14863	.12014	.22718	-,11243
.01964	.03027	-,05866	03662	.05112	01256	.00131	00930
.15456	-,16619	-, 75158	.66713	.59752	56878	08748	.22881
.21586		.19722	23537	07623	.06640	73105	.61691
.32139	29233	20923	.29246	01967	00760	938	04655
.18778	09700	09134	.04205	34222	.33680	.24419	22873
45724	.46156	1.00000	91192	61246	.50680	.29627	24268
. 29625	25814	.20903	27272	62749	.57917	-,37235	.35083
.63456	52692	69756	.68432	39926	.38732	92	01996
.85295		-,16309	.07449	66763	.55854	. 75212	66064
.01341		69258	.73944	24526	.31619	-,23375	.27878
.46264	-	.48592	-,32340	34504	.26844	.20783	11532
08616	.09817	23051	.29481	31636	.36774	.66015	67401
,71557	•	10428	.05072	14769	.14339	-,33023	.15049
-,13876	.21766	-,35172	.41962	.41336	44316	00564	.08085
21176	.14628	.56232	53412	30132	.30024	,16136	14340
35403	,33924	09190	• 05492	.17061	14795	07255	.05255
.02042	.05658	19098	.16433	04454	.10904	.47259	-,45599
09366	014	0	286	S	06540	25990	.17584
.01721	04248	612319	.04622	.08226	0567A	0	.06307
.05532	04627	.10704	05654	.18944	-, 12552	-,21587	.08893

1 1 1 1				27.78702	. 2	ON (DR)	SUPPRESSION
05596	.08229	,135.37	23040	06283	11101	-,74236	.71437
,31504	29348	.12761	.02752	18562	.23980	.61100	68414
01401	.05017	70394	.81407	.67606	70139	.58095	64833
16201	.19438	.00065	08706	03981	04970	.19496	22538
27290	.27441	12809	.07265	39540	.38672	.28314	38829
.45193	44997	65381	. 12575	20186	.22171	.61217	69197
-, 33322	.28937	01225	.00511	11226	06810	-,10008	.10448
.26874	36117	-,36541	.37051	-,05433	00264	,21236	1A137
-,12501	.18070	73991	.88585	.24058	27916	.11054	12145
.26283	25002	.17408	09353	.11038	14436	-, 12835	.10385
.32135	30040	-,37896	.47511	46634	.44789	.53126	48409
46373	.56144	.28414	20838	.77148	85603	. 50054	59254
66909	.61833	-,31995	.35919	.09209	09391	.58803	77434
83172	60046.	.00807	01732	.23669	12872	37550	.26865
.82048	-,91709	06534	.09616	34375	.370AS	83896	.83810
.13129	18275	19790	.31745	.38641	-,38254	.32045	-,22439
07619	.08782	.07126	16196	05864	.14395	-,01040	.02558
.0220A	12947	.02239	.02804	07086	.02286	.03012	-,00656
07408	\$1680.	.04401	05236	02213	.11396	.07039	10077
.06568	-,15183	02218	.02086	05978	.09358	00186	05894
00064	03672	04051	•00000	06580	.17102	03743	,12366
.10245	-,24319	.04412	11379	07357	.09756	05677	.00719
04445	.02190	07550	.06713	04004	.02766	06506	.10980
01036	03068	02219	.00419	02308	04834	05312	+0860
04735	.01390	-,00699	02128	05028	.08360	01537	•05559
96900.	00850	.03518	07293	00777	02706	02029	05981
07960	.09387	08493	.12070	03301	00931	00970	02752
05851	.11254	02415	.06628	.01491	.02994	.07709	09777
.06030	06023	.02760	07733	.00735	.10222	00154	07324

\$000\$.50034	\$6005	.50186	.503n7	.5045B	.50640	.50851
.51093	.51364	.51664	.51994	.52353	.52741	.53157	. 53602
.54076	.54577	.55105	.55661	.56244	.56853	.57489	.5815
59837	59549	.60285	.61046	.61830	.62637	.63467	.64319
65193	.66088	.67004	.67939	.6A894	.69868	.70860	.71870
.72897	.73941	.75000	.76074	.77163	.7H266	. 19342	.8051
.81651	.82802	.83964	.85136	.86317	.87506	. 687	90668
91115	.92330	93550	.94773	00096	.97229	98460	26966.
1.00924	1.02155	1.03385	1.04613	1.05838	1.07060	1.08278	1.09490
1,10697	1,11897	1,13090	1.14275	1,15451	1,16618	1.11774	1,1892
1.20055	1.21177	1.22287	1,23383	1.24465	1,25531	1,26583	1,27618
1.28637	1,29638	1,30621	1,31585	1,32531	1.33456	1,34362	1,35246
1,36109	1.36950	1.37769	1,38565	1,39337	1.40086	1.40810	1.41509
1.42183	-1.42832	1.43454	1.44051	1.44620	1,45162	1.45677	1.4616
1.46624	1.47054	1.47457	1.47830	1.48175	1.48490	1.48776	1.49032
1.49258	1.49454	1.49621	1.49757	1,49863	1.49939	1.49985	1.50000
1.49985	1.49939	1,49863	1.49757	1.49621	1.49454	1.49258	1.49032
1.48776	1.48490	1,48175	1.47830	1.47457	1.47054	1.46624	1.4616
1.45677	1,45162	1,44620	1.44051	1.43454	1.42832	1.42183	1.41509
1.40010	40086	1.39337	1.38565	1.37769	1,36950	1,36109	1,3524
1.34362	1,33456	1,32531	1,31585	1,30621	1.29638	1.28637	1,27618
1.26583	1,25531	1.24465	1,23383	1.22287	1.21177	1.20055	1,1892
1-17774	1.16618	1,15451	1,14275	1.13090	1.11897	1.10697	1.09490
1.08278	1.07060	1,05838	1.04613	1.03385	1.02155	1.00924	. 99692
.98460	.97229	00096	.94773	.93550	.92330	.91115	90668*
588792	.87506	86317	85136	.83964	.82802	.81651	.8051
.79382	.78266	.77163	.7607¢	.75000	.73941	.72897	.7187(
.70860	.69868	.68894	.67939	*0029	.66088	.65193	.6431
63467	.62637	.61830	.61046	.60285	.59549	.58837	.58150
.57489	.56853	.56244	.55661	.55105	.54577	.54076	.5360
.53157	.52741	.52353	*6615 °	.51664	.51364	.51093	.5085
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	-20 2224 -30 43202 -30 41420 -31 OFF30 -34 A0672 -37 33267
-29.63283 -30.51628 -31.95538 -34.08572 -35.5757	TOTAL PRODUCT OFFICE OF
-32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827	-32.68465 -32.10396 -31.51437 -30.92793 -30.36092 -29.83827
-32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827	-32.68465 -32.10396 -31.51437 -30.92793 -30.36092 -29.83827
COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE	-32.68465 -32.10396 -31.51437 -30.92793 -30.36092 -29.83827
COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE	COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE -32.68465 -32.10396 -31.51437 -30.92793 -30.36092 -29.83827
-5.24691 -6.31034 -7.40009 -8.48114 -9.53406 -10.54722 - COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE -32.368465 -32.10396 -31.51437 -30.92793 -30.36092 -29.83827 -	-5.24691 -6.31034 -7.40009 -8.48114 -9.53406 -10.54722 - COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE -32.68465 -32.10396 -31.51437 -30.92793 -30.36092 -29.83827 -
-1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 -5.24691 -6.31034 -7.40009 -8.48114 -9.53406 -10.54722 - COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE	-1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 -5.24691 -6.31034 -7.40009 -8.48114 -9.53406 -10.54722 - COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE -32.68465 -32.10396 -31.51437 -30.92793 -30.36092 -29.83827 -
-4.79063 -3.82824 -3.12086 -2.65897 -2.38732 -2.23139 -1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 -5.24691 -6.31034 -7.40009 -8.48114 -9.53406 -10.54722 - COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE	-4.79063 -3.82824 -3.12086 -2.65897 -2.38732 -2.23139 -1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 -5.24691 -6.31034 -7.40009 -8.48114 -9.53406 -10.54722 - COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE -32.68465 -32.10396 -31.51437 -30.92793 -30.36092 -29.83827 -
-15,43969 -14,17362 -12,85739 -11,49469 -10,09601 -8,68230 -4,79063 -3,82824 -3,12086 -2,65897 -2,38732 -2,23139 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -5,24691 -6,31034 -7,40009 -8,48114 -9,53406 -10,54722 -2,24691 -6,31034 -7,40009 -8,48114 -9,53406 -10,54722 -2,24691 -3,268465 -32,10396 -31,51437 -30,90793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,90793 -30,36092 -29,83827 -	-15,43969 -14,17362 -12,85739 -11,49469 -10,09601 -8,68230 -4,79063 -3,82824 -3,12086 -2,65897 -2,38732 -2,23139 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -5,24691 -6,31034 -7,40009 -8,48114 -9,53406 -10,54722 -2,24691 -6,31034 -7,40009 -8,48114 -9,53406 -10,54722 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -30,36092 -32,06572 -37,33527
-15,43969 -14,17362 -12,85739 -11,49469 -10,09601 -8,68230 -4,79063 -3,82824 -3,12086 -2,65897 -2,38732 -2,23139 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -5,24691 -6,31034 -7,40009 -8,48114 -9,53406 -10,54722 -2,24691 -6,31034 -7,40009 -8,48114 -9,53406 -10,54722 -32,68465 -32,10396 -31,51437 -30,90793 -30,36092 -29,83827 -	-15,43969 -14,17362 -12,85739 -11,49469 -10,09601 -8,68230 -4,79063 -3,82824 -3,12086 -2,65897 -2,38732 -2,23139 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -5,24691 -6,31034 -7,40009 -8,48114 -9,53406 -10,54722 -2,24691 -6,31034 -7,40009 -8,48114 -9,53406 -10,54722 -2,268465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465
MAIN-PORT RASEBAND CHANNEL AMPLITUDE RESPONSE -15.43969 -14.17362 -12.85739 -11.49469 -10.09601 -8.68230 -4.79063 -3.82824 -3.12086 -2.65897 -2.38732 -2.23139 -1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 -5.24691 -6.31034 -7.40009 -8.48114 -9.53406 -10.54722 - COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE	MAIN-PORT RASEBAND CHANNEL AMPLITUDE RESPONSE -15,43969 -14,17362 -12,85739 -11,49469 -10,09601 -8,68230 -4,79063 -3,82824 -3,12086 -2,65897 -2,38732 -2,23139 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -5,24691 -6,31034 -7,40009 -8,48114 -9,53406 -10,54722 - COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -
.65526 -15.43969 -14.17362 -12.85739 -11.49469 -10.09601 -8.68230 .96633 -4.79063 -3.82824 -3.12086 -2.65897 -2.38732 -2.23139 .05608 -1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 .25410 -5.24691 -6.31034 -7.40009 -8.48114 -9.53406 -10.54722 - COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE	-15,43969 -14,17362 -12,85739 -11,49469 -10,09601 -8,68230 -4,79563 -3,82824 -3,12086 -2,65897 -2,38732 -2,23139 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -5,24691 -6,31034 -7,40009 -8,48114 -9,53406 -10,54722 -2,24691 -6,31034 -7,40009 -8,48114 -9,53406 -10,54722 -2,268465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -30,2252 -29,83827 -30,2252 -20,225
### ##################################	## ## ## ## ## ## ## ## ## ## ## ## ##
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-44.57906 -44.33565 -44.74121 -44.76089 -44.84375 -45.24339 -4 RASEBAND CHANNEL AMPLITUDE RESPONSE MAIN-PORT RASEBAND CHANNEL AMPLITUDE RESPONSE -15.43969 -14.17362 -12.85739 -11.49469 -10.09601 -8.68230 -4.79363 -3.82824 -3.12086 -2.65897 -2.25224 -2.71445 -1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 -5.24691 -6.31034 -7.40009 -8.48114 -9.53406 -10.54722 COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE	-44,57906 -44,33565 -44,74121 -44,76089 -44,84375 -45,24339 -4 RASEBAND CHANNEL AMPLITUDE RESPONSE -15,43969 -14,17362 -12,85739 -11,49469 -10,09601 -8,68230 -4,79363 -3,82824 -3,12086 -2,65897 -2,38732 -2,23139 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -5,24691 -6,31034 -7,40009 -8,48114 -9,53406 -10,54722 -2,24691 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465 -32,10396 -31,51437 -30,92793 -30,36092 -29,83827 -32,68465
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COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE -44,7855 -49,00256 -47,98703 -47,16280 -46,40019 -45,26120 -44,37779 -43,94479 -44,22459 -44,42810 -45,48190 -47,53238 -51,23555 -51,51321 -49,08292 -47,04507 -45,78110 -44,57906 -44,33565 -44,74121 -44,76089 -44,84375 -45,24339 -44,57906 -44,33565 -44,74121 -44,76089 -2,24335 -2,23139 -4,79063 -3,82824 -3,12086 -2,65897 -2,38732 -2,23139 -1,97748 -1,97748 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97748 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -5,24691 -6,31034 -7,4009 -8,48114 -9,53406 -10,54722 -2,64465 -32,10366 -31,51437 -30,92793 -30,36092 -29,83827 -	COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE -44,37779 -43,94479 -44,42810 -45,48190 -47,53238 -45,2779 -43,94479 -44,42810 -45,48190 -47,53238 -45,5796 -44,33565 -44,74121 -44,76189 -44,84375 -45,24339 -44,5796 -44,33565 -44,74121 -44,76189 -44,84375 -45,24339 -44,5796 -44,33565 -44,74121 -44,76189 -44,84375 -45,24339 -48,5796 -44,33565 -44,74121 -44,76189 -44,84375 -2,2339 -15,4369 -14,17362 -12,85739 -11,49469 -10,09601 -8,68230 -46,79363 -3,82824 -3,12086 -2,55897 -2,33732 -2,23139 -1,97848 -1,97848 -1,91513 -1,90377 -1,99607 -2,55224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,55224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,55224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,55224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,55224 -2,71345 -1,97848 -1,91513 -1,90377 -1,99607 -2,55224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,55224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,55224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,55224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,55224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,55224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,55224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,55224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,55224 -2,71445 -1,97848 -1,99517 -1,99607 -2,552524 -2,71445 -1,97848 -1,99517 -1,99607 -2,552524 -2,71445 -1,97848 -1,99517 -1,99607 -2,552524 -2,71445 -1,97848 -1,99517 -1,99607 -2,953406 -10,59607 -2,95907 -2,95
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HAIN-PORT BASEBAND CHANNEL AMPLITUDE RESPONSE -30,16212 -28,35980 -26,52783 -24,70956 -22,88308 -21,04797 -1 -11,33837 -11,07288 -10,89269 -10,80316 -10,89853 -11,19811 -1 -13,30921 -14,25012 -15,21103 -16,18156 -17,13153 -18,03403 -1 -13,30921 -14,25012 -15,21103 -16,18156 -17,13153 -18,03403 -1 -49,7855 -49,00256 -47,98703 -47,16280 -46,40109 -45,26120 -44,3779 -43,9479 -44,2810 -45,4810 -45,26120 -45,27906 -44,33545 -44,71100 -45,48190 -45,24339 -44,57906 -44,33565 -44,7121 -44,7689 -44,8435 -45,24339 -44,57906 -44,33565 -44,7121 -44,7689 -44,8435 -45,24339 -115,4369 -14,17362 -12,85739 -11,49469 -10,09601 -8,68230 -4,79663 -3,82824 -3,12086 -2,65897 -2,38732 -2,23139 -1,9748 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,9748 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,9748 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,9748 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,9748 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,9748 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,9748 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,9748 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,9748 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,9748 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,9748 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,9768 -2,24691 -6,31034 -7,0009 -8,48114 -9,53406 -10,59608 -10,5408 -10,5	HAIN-POHT BASEBAND CHANNEL AMPLITUDE RESPONSE -30,16212 -28,35990 -26,52783 -24,70956 -22,88368 -21,04797 -1 -13,33837 -11,07288 -10,89269 -10,80316 -10,89853 -11,19811 -1 -13,30921 -14,25012 -15,21103 -16,18156 -17,13153 -18,03403 -1 -13,30921 -14,25012 -15,21103 -16,18156 -17,13153 -18,03403 -1 -13,30921 -14,25012 -15,21103 -16,18156 -17,13153 -18,03403 -1 -40,7855 -40,00256 -41,98703 -47,16280 -46,40019 -45,26120 -44,37779 -43,9479 -44,22459 -44,426110 -45,44190 -47,53288 -45,2355 -51,51321 -40,73190 -40,08292 -47,04507 -45,78139 -4,44,57906 -44,33565 -44,74121 -44,77089 -44,84375 -45,24339 -4,44,57906 -44,33565 -44,74121 -44,77089 -44,84375 -45,24339 -4,44,79063 -3,82684 -1,91513 -1,99377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,97848 -1,91513 -1,90377 -1,99607 -2,25224 -2,71445 -1,99607 -2,26999 -10,09601 -
HAIN-POHT BASEBAND CHANNEL AMPLITUDE RESPONSE -30,16212 -28,35990 -26,52783 -24,70956 -22,88368 -21,04797 -1 -16,16315 -14,87927 -11,88285 -13,13818 -12,61402 -12,23330 -1 -11,33837 -11,07288 -10,89269 -10,80316 -10,89853 -11,19811 -13,30921 -14,25012 -15,21103 -16,18156 -17,13153 -18,03403 -1 COMPOSITE RASEBAND CHANNEL AMPLITUDE RESPONSE -49,7855 -49,00256 -47,98703 -47,16280 -46,40019 -45,26120 -45,123555 -45,98479 -44,76089 -44,84375 -45,24339 -44,57706 -44,33565 -44,74121 -44,776089 -44,84375 -45,24339 -44,57706 -44,33565 -44,74121 -44,776089 -44,84375 -45,24339 -11,49469 -10,09601 -8,68230 -44,77063 -3,82824 -3,12086 -2,65897 -2,33722 -2,73139 -1,97748 -1,91513 -1,91513 -1,99607 -2,25224 -2,74455 -1,97748 -1,91513 -1,99607 -2,25224 -2,74455 -1,97748 -1,91513 -1,99077 -2,25224 -2,74455 -1,91513 -1,9151	## MAIN POHT RASEBAND CHANNEL AMPLITUDE RESPONSE -30.16212 -28.35990 -26.52783 -24.70956 -22.88368 -21.04797 -1 -15.16315 -14.87927 -13.88285 -13.13818 -12.61402 -12.23330 -1 -11.33837 -11.07288 -10.89269 -10.80316 -10.89853 -11.19811 -1 -13.30921 -14.25012 -15.41103 -16.18156 -17.13153 -18.03403 -1 -13.30921 -14.25012 -15.41103 -16.18156 -17.13153 -18.03403 -1 -40.7855 -40.00256 -41.98703 -41.16280 -46.40019 -45.26120 -44.37779 -43.94779 -44.22459 -44.42810 -45.48110 -45.48110 -45.48110 -45.48110 -45.28139 -44.57906 -44.33779 -43.39479 -44.7949 -44.84375 -45.28139 -44.57906 -44.33565 -44.74121 -44.76089 -44.84375 -45.28339 -44.57906 -44.33565 -44.74121 -44.76089 -44.84375 -45.28339 -4.76089 -44.84375 -45.28339 -4.76089 -14.17362 -12.85739 -11.49469 -10.09601 -8.68230 -2.23739 -1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 -1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 -1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 -1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 -1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 -1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 -1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.71445 -1.97848 -1.91513 -1.90377 -1.99607 -2.25224 -2.7145 -1.90377 -1.99607 -2.25224 -2.7145 -1.90377 -1.99603 -3.0092 -2.9983827 -2.264455 -3.7203 -3.0092 -3.
### PASEBAND CHANNEL AMPLITUDE RESPONSE -30,16212 -28,35940 -26,32783 -24,7056 -22,88308 -21,04797 -1 -11,33837 -11,07288 -10,89269 -10,80316 -10,89833 -11,19811 -1 -13,30921 -14,25012 -15,21103 -16,18156 -17,13153 -18,03403 -1 -13,30921 -14,25012 -15,21103 -16,18156 -17,13153 -18,03403 -1 -49,7855 -49,00256 -47,98703 -47,16280 -46,4019 -45,26120 -44,42917 -43,7479 -43,9479 -44,98703 -47,16280 -45,40190 -45,76110 -45,76110 -45,7706 -44,33555 -51,5127 -49,73190 -49,74089 -44,84375 -45,24339 -44,57706 -44,33555 -51,5127 -44,76089 -44,84375 -45,24339 -44,57706 -44,33565 -44,74121 -44,77089 -44,84375 -45,24339 -44,77063 -3,8408 -14,7108 RESPONSE -15,43969 -14,17362 -12,85739 -11,49469 -10,09601 -8,68230 -4,70063 -3,82624 -3,12086 -2,65897 -2,38732 -2,23139 -4,70063 -3,82624 -3,12086 -2,65897 -2,38732 -2,23139 -4,70063 -3,926340 -10,59608 -1,59163 -1,59163 -1,59164 -9,53406 -10,55085 -2,68807 -2,58691 -2,58691 -6,31034 -7,40009 -8,48114 -9,53406 -10,59608 -2,68807 -2,58691 -8,5969 -10,59608 -1,59163 -1,59163 -1,59163 -10,59793 -19,36092 -29,83877 -1,59163 -10,59608 -1,59163 -1,59163 -1,59163 -10,59793 -19,36092 -29,83877 -1,59163 -10,59608 -1,59163 -1,59163 -10,59793 -19,36092 -29,83877 -1,59163 -10,59608 -1,59163 -10,59793 -19,36092 -29,83877 -1,59163 -10,59793 -19,36092 -29,83877 -1,59163 -10,59793 -19,36092 -29,83877 -1,59163 -10,59793 -19,36092 -29,83877 -1,59163 -10,59793 -19,36092 -29,83877 -1,59163 -10,59793 -19,36092 -29,83877 -1,59163 -10,59793 -19,36092 -29,83877 -1,59163 -10,59793 -19,36092 -29,83877 -1,59163 -10,59793 -19,39092 -10,39082	HAIN-POHT RASEBAND CHANNEL AMPLITUDE RESPONSE -30,16212 -28,35980 -26,52783 -24,7056 -22,88388 -21,04797 -11,3383 -12,1313818 -12,61402 -12,23330 -11,33873 -11,07288 -10,89269 -10,80316 -10,89953 -11,19811 -12,13397 -11,07288 -10,89269 -10,80316 -10,89953 -11,19811 -13,30921 -14,25012 -15,21103 -16,18156 -17,13153 -18,03403 -12,43759 -49,00256 -47,98703 -47,16280 -46,40019 -45,26120 -46,37759 -43,9479 -44,22459 -44,26210 -45,48190 -47,3523 -42,37759 -43,39479 -44,76879 -44,84375 -45,28139 -44,57906 -44,84375 -45,28139 -44,57906 -44,84375 -45,28139 -44,79063 -3,82824 -3,12086 -2,65897 -2,38732 -2,23139 -1,97748 -1,91513 -1,90377 -1,99607 -2,5524 -2,71445 -1,97748 -1,91513 -1,90377 -1,99607 -2,5524 -2,71445 -1,97748 -1,91513 -1,90377 -1,99607 -2,5524 -2,71445 -1,97748 -1,91513 -1,90377 -1,99607 -2,5524 -2,71445 -1,97748 -1,91513 -1,90377 -1,99607 -2,5524 -2,71445 -1,97748 -1,91513 -1,90377 -1,99607 -2,5524 -2,71445 -1,97748 -1,91513 -1,90377 -1,99607 -2,5524 -2,71445 -1,97748 -1,91513 -1,90377 -1,99607 -2,5524 -2,71445 -1,97748 -1,91513 -1,90377 -1,99607 -2,5524 -2,71445 -1,97748 -1,91513 -1,90377 -1,99607 -2,5524 -2,71445 -1,97748 -1,91513 -1,90377 -1,99607 -2,5524 -2,71445 -1,97748 -1,91513 -1,90377 -1,99607 -2,5524 -2,71445 -1,97748 -1,91513 -1,90377 -1,90607 -2,5524 -2,71445 -1,97748 -1,91513 -1,90377 -1,90607 -2,5524 -2,71445 -1,97748 -1,91513 -1,90377 -1,90607 -2,5924 -2,71445 -1,97748 -1,91513 -1,90377 -1,90607 -2,5924 -2,71445 -1,97748 -1,91513 -1,90377 -1,90607 -2,5924 -2,71445 -1,97648 -1,91513 -1,90377 -1,90607 -2,983877 -1,97848 -1,91513 -1,90377 -1,90607 -2,983827 -2,71445 -1,97648 -1,91513 -1,90377 -1,90607 -2,983827 -2,71445 -1,97648 -1,91513 -1,90377 -1,90607 -2,983827 -2,71445 -1,97648

- Parket A

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FIELD PATTERN PEFORE AND AFTER BCH ADAPTATION ABOUT INTERFERENCE	!!!
ABOUT	
ADAPTATION	
BCH	
AFTEH	
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PEFOPE	
PATTERN	
FIELD	

1 I	PATIEN	REFORE AND	AFTER BCK	ADAPTATIO	FIELD PATTENN REFORE AND AFTER BCK ADAPTATION ABOUT INTERFERENCE	TERFERENCE	-
			MAIN FIELD) PATTERN			
1							
44.87498	44.87498 -22.91161		-24,32169	44.8A2A0	-26,02714	44 AB470	10010 901
44.89061	-30,58412		-35,12675	44.ROHA2		0/0000	102/0.02-
44.90623	-37,76054	44.91014	-32,07393	44.01405	-28 FOOL3	DC 20 44	11106.74
44.92186	-24.73946		-23.33780	44 02047	530000	00010 · ·	-20.51216
44.93748	-19.96809		100000	19626044	56600°22-	44.43358	-20.88618
44.95311	-16 91776	451440 44	25050051	94.94530	•	44.94920	-17,57083
44 04872	0//16-01-		-10.31866	44.96092	7	44.96483	-15,22130
71558644	58/1/**	•		44.97655	-13,82789	44.98045	-13.37713
CE +86 ***		44.98827	-12,62630	44.99217	-12.26140	44 . 005 DB	-11 04240
£00000°	-11.59961	45.003A9	-11.44618	45.00780	-11.01364	45 01170	-11.75547
45.01561	-10.45701	45.01952	-10.23641	45.02342	0 04320	0/110.04	10762.01
-45,03123	-9.48957	45.03514		45.03005	100000	45.06733	-7.12084
45.04686	-8,66108	45.05077	-R. 40413	45 054K7	CV000.Y*	56240°C4	-8.86177
45.06248	_	45.06430		10400004	5064200	45.03858	-8.09089
A5. 07811	1	**************************************		45.07030	-1.05774	45.07420	-7.50201
1101000		2020000		45.08592	-7.07059	45.08983	-6.96996
5/560.00	-	42.09764		45,10155	-6.61768	45,10545	-6.51336
45.10936	-6.40508	45.11327	-6.31509	45.11717	-6.21940	45,12108	45,12108 -6,12637
		ວັ	COMPOSITE FIFLD PATTERN	FLD PATTER	Z		
					. !		
44,87498	44,87498 -38,14034	-	44.87889 -37.82819	44.88280	44 - AB280 - 37 - 48040	0F700 **	
44.89061	-37,80243	-	44.89452 -36.88557	44.80442		0/0000	06104.16-
44.90623	-37,66563	-	-37,00244	44.01405		4404050	96201.06-
44,92186	-36,61916		44.92577 -37.02135	44.02047	44.91403 =38.08327 44.92947 =34.04353	56116.44	-36.53522

		i			1		
	-38,14034	44.87889	44.87889 -37.82819	44 00200	04004 761	4 1 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	
AA AONAI	C7600 LE-	CU400 44		203000	01101111	0/000.	-3/.4615(
100400	C+200° 15-	20460***	-30.88557	44.89842	-36,86397	££ 600.44	10CUL AF-
44.90623	-37.66563	44.91014	-37.00244	44 01405	*CC00 76-		16 10 1 0 C
A4 02104	71017 75		**************************************	COATAGAL	1250.05-	24.14.45	-36.5352
0013404	07610905-	11024.44	-3/-02135	44.92967	-36.86353	44.0335A	126 95
44.93748	-37.28210	44.94139	-37.503A6	44 94530	01077 26-	00000	TCCO TOC
1129-44	מטרטר פר	C & C & C & A &		20044	0+000-15-	026+6**	-38.01903
	045454051	20164.	220,040,0	44.96092	-39,15666	44.964A3	10400.04-
F/404.	-40.52791	44.97264	-43.32147	44.97655	-42.41411	44 00045	
44.98436	-44.66ASA	44.09427	-4E 22740	00000	17074034	C+004 ***	-46.433%
00000		13000	00/55.00	1766.44	-46.3015]	44.99608	-48.75017
ログナググ・ナナ	-50.10388	45.003A9	-45.33383	45.007A0	ST. ASSAB	46 01170	7664 (3-
45.01561	-47.4A7A1	45.01052	-44 20E03			0.110.0	1204.16-
AG 02123		300000	50C030+++	24520 °C+	16266.54	45,02733	-41.66835
42.03163	-+0.43584	42.03514	-39,39371	45,03905	-38-19415	45.04205	-37 A4106
45.04686	-36.47298	45.05077	-35.37R52	45 05447	24 63671		
45,04248	AC771 FF-	45 04430		1040000	110000000	40,00408	-34.67171
010000	0311100	45000 °C	11666.36	45.07030	-31,78815	45.07420	-31,25069
45.07811	-30.0000B	45.08202	-29.98918	45.0A592	-20. 78421	C0000 44	E 7011 0C-
45.09373	-28.64655	45,00764	-20 12344			5040000	19611.62-
75001 34	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	P. C. C. C. C. C. C. C. C. C. C. C. C. C.	-CO. 1 C 304	66707.64	-21.418B	45.10545	-27.27008
42.10430	-50.43004	45.11327	-26.45731	45,11717	-26.08177		-25.75650
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INTERFERENCE
ABOUT
BCH ADAPTATION
AFTER BCH A
AFTE
AND
AEFOPE
PATTERN
TELO

			MAIN FIELD	đ			
9,87499	-2,32133	9.87890	-2.86640	9.88281	-3,45642	9.88671	-4.09233
9.89062	1	9.89452	-5.54609	9.89843	-6.38737	9.90234	-7,32136
9.90625		9.91015	-9.58602	9.91406	-10,99620	9.91796	-12,68318
9,92187		.92578	-17.56418	9.92968	-21.75583	9.93359	-29.92409
9.93749		9.94140	-23,30136	9.94531	-18.53484	9.94921	-15,47561
9,95312		9.95703	-11.45302	9.96093	-9.98432	9.96484	-8.73459
9.96875		9.97265	-6,68963	9.97656	-5.83354	9.98046	-5.05833
9.98437	1	9.98828	-3,70984	9.99218	-3,11591	60966.6	-2,56558
10.00000	-2.05608	10,00390	7	10.00781	-1.13508	10.01171	71762
10,01562	-,32580	10,01953		10.02343	.38935	10.02734	.71681
10,03124	1.02605	10,03515	_	10.03906	1.59518	10.04296	1.85667
10.04687	2,10461	10.05078	~	10.05468	2.56164	10,05859	2,77231
10,06250	2,97135	10.06640		10.07031	3,33700	10.07421	3,50537
10.07812	3.66414	10,08203	3.81384	10.08593	3,95449	10.08984	4.08673
10.09374	4.21071	10,09765	4,32641	10,10156	4.43475	10,10546	4.53541
10,10937	4.62R33	10.11328	4.71412	10.11718	4.79284	10,12109	4.86454
		ວັ	COMPOSITE FIELD	ELD PATTERN	Z		
00110	22026				ı		
V-510.V	Canac • I	060100	1016333	16244	+C//D*	1/000*	106 700
9.89062	.34903	9.89452	•06506	9.89843	23371	9.90234	54608
9.90625		9.91015	-1.22179	9.91406	-1.58666	9.91796	-1.97075
9,92187		9.92578	-2.80782	9.92968	-3.26701	6,93359	-3.74768
9.93749		9.94140	-4.81832	9.94531	-5.41165	9.94921	-6.05264
9,95312		9.95703	-7.49954	660966	-8,32817	9.96484	-9.24529
9.96875	۱	9.97265	-11.43480	9.97656	-12,77526	9.98046	-14,36363
9.98437		9.98828	-18.78267	9.99218	-22,25862	60966.6	-28,11920
10,00000	-54,88399	10.00390	-28,96068	10.00781	-22.77150	10.01171	-19.20776
10.01562	-16,70735	10.01953	-14.79958	10.02343	-13.22743	10.02734	-11,91891
10,03124	-10,79452	10.03515	-9.80941	10.03906	-8.93699	10.04296	-8.15520
10.04687	-7.44717	10,05078	-6.80340	10.05468	-6.21220	10.05859	-5.66830
10,06250	-5.16668	10.06640	-4.70848	10.07031	-4.27060	10.07421	-3.86693
10,07812	-3,49012	10.08203	-3.13747	10.08593	-2.80760	10.08984	-2.49797
10,09374	-2,20736	10.09765	-1.93501	10.10156	-1.67816	10,10546	-1.43707
10,10937	-1.21109	10.11328	99872	10.11718	79923	10.12109	61231

			CIRTA STAN	DATTEUN			
4	35248	-12109	47.40089	11719	47.44769	-,11328	47.49290
4	7,53650	10547	47,57854	-,10156	47,61899	09766	.657A
•	615697	08984	47.73094	08594	47,76514	-,08293	47.79778
+	7.82887	07422	47.85843	07031	47.88644	06641	47.91292
7	7,93787	.0585	47.96129	05469	•	05078	48.00356
4	8.02240	04297	48.03973	03906	48.05554	035	48.06985
4	3.08266	02734	48.09395	02344	48,10371	01953	48.11198
•	8,11876	01172	48,12401	00781	48.12778	00391	48.13004
4	8,13077	.00391	~	.00791	48.12778	.01172	48.12402
4	8,11876	.01953	48.11198	.02344	48,10371	.02734	48.09395
•	8.08766	03516	48.06985	90660	48.05554	.04297	48.03973
•	05240	05078	.0035	.05469	47,98318	.05859	47.96129
•	7.93787	.06641	.9129	.07031	88	.07422	47,85843
07812 47	7.82847	.08203	47.79778	.08594	47,76514	.08984	.7309
•	7,69519	.09766	6578	.10156	47,61899	$\overline{}$	v.
4	7.53650	.11328	4929	.11719	47.44.769	.12109	47.40089
		00	COMPOSITE FIL	FIELD PATTERN	Z (
4	7.34837	12109	47.39626	11719	47		47.48715
•	S	7	47,57175	10156	•		47.65004
		- 089A4	47,72211	08594	47,75581		47.78796
•	•	07422	47.84767	07031	47,87521		47.90123
47	7,92572	05859	47.94868	05469	47.97014	15078	47.99008
04687 46		04297	48.02544	03906	.040		48.05473
•	8,06714	02734	48.07803	02344	48.0A743	01953	48.09534
4	8,10175	01172	48.10664	007H1	48,11006	00391	48,11197
•	8,11238	.00391	48,11131	.00781	48,10876	.01172	48.10468
4	48.09914	.01953	48.09207	.02344	48,08353	.02734	48.07347
*	R.06194	.03516	48.04889	.03406	48.03433	.04297	48.01830
.04687 4	8,00073	.05078	47.98167	.05469	47,96109	.05859	47.93931
4	7,91539	.06641	47.89027	.07031	47,86365	.07422	47.83546
•	17,80579	.08203	47.77454	.08594	47.74179	48680	4/0
•	7.67162	.09766	47.63422	.10156	47,59525	.10547	47.55473
•			•			:	() ! ! !

Title Page

PROCESSING ADAPTIUE PROCESSING BCR

BLINKING SOURCE EXAMPLE (See Figure 3-1)

1 CONTINOUS (10°) 1 BLINKING (45°) SOURCES

0.1% RF BANDWIDTH

AUXILIARY PORTS

TAP WEIGHTS

1/PORT

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Figure 3-3

Relative Signal Amplitude Before and After BCR Adaptation

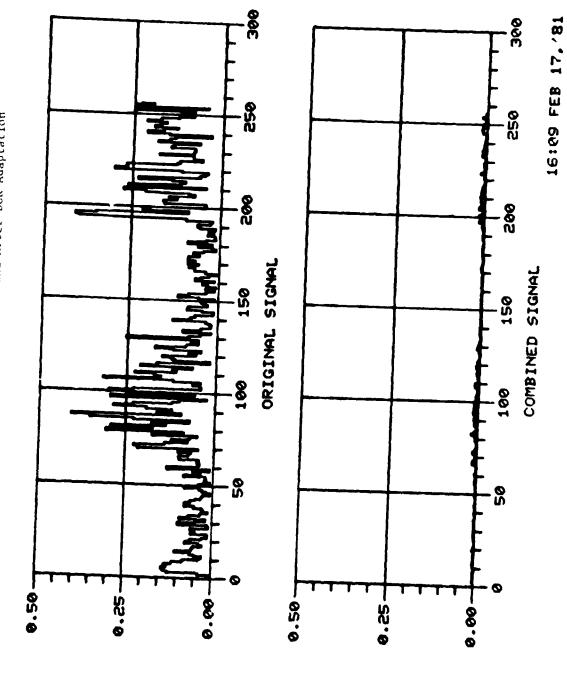
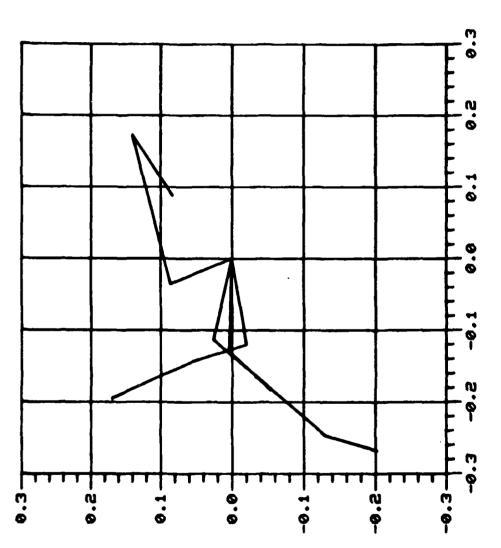


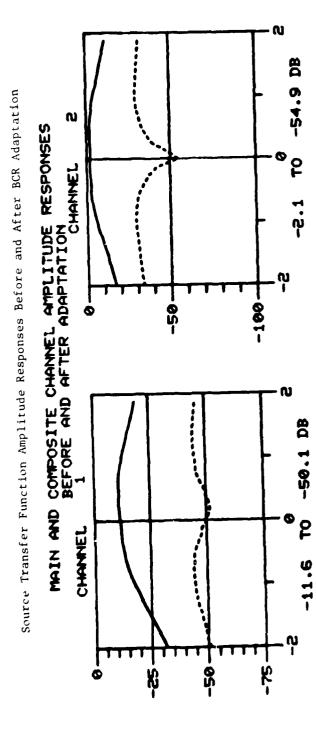
Figure 3-3 (Cont'd)



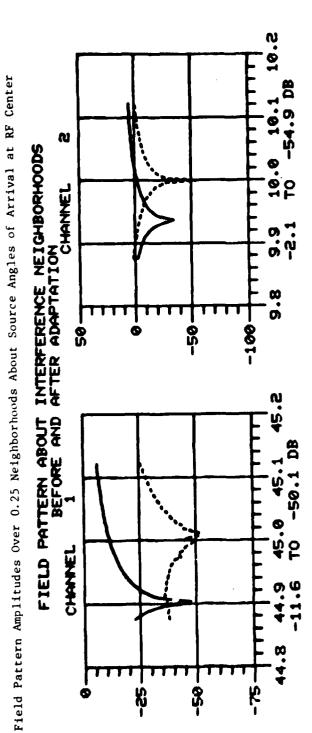
EVOLUTION OF ADAPTIVE WEIGHTS

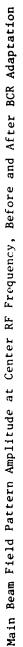
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Figure 3-3 (Cont'd)



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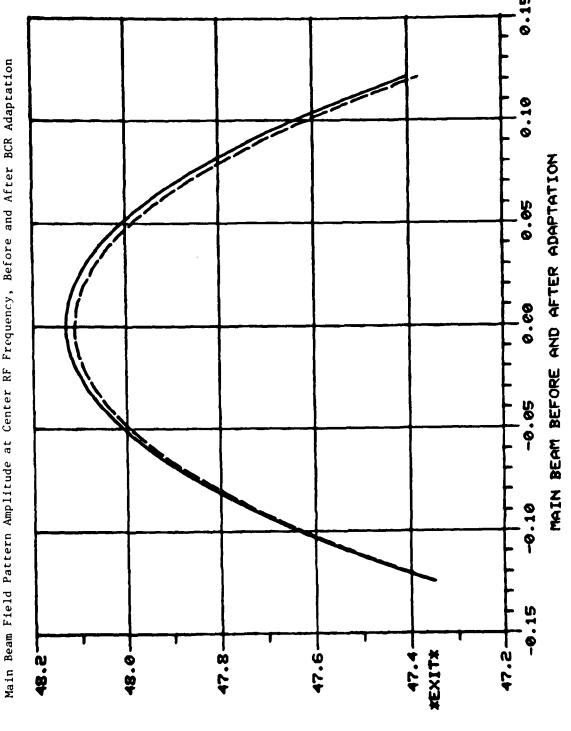


Figure 3-3 (Cont'd)

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3.1.2.1 Equal Source Strengths

Figure 3-4 defines the scenario and system description involving six sources of equal strength and six 1-tap ports operating at a 0.1% RF bandwidth. Figure 3-5 shows the observed BCR convergence behavior. Note that from the practical viewpoint of combined power suppression, the BCR process has converged in the sixth iteration. However, it takes an additional iteration to cross below the relative gradient threshold of -60 dB to declare convergence. Figure 3-6 summarizes, graphically, the overall BCR performance for this example.

3.1.2.2 Unequal Source trengths

Figure 3-7 defines the scenario and system description that is very similar to that of the revious example with the exception that it involves unequal source strengths. Of interest is the BCR convergence behavior shown in Figure 3-8. Note the distinct rise in the relative gradient metric at the fifth iteration accompanied by a rather insignificant drop in relative combined power. The slow convergence behavior beyond the fourth iteration is a manifestation of an ill-conditioned covariance matrix which is attributed to the large dynamic range over the incident source powers. It should also be noted that the nulling performance in the present example is approximately 1.5 dB worst than that of the previous example. This may also be due to the numerically ill-conditioned nature of the present example.

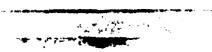
In evaluating the nulling performance in the two examples above, it is interesting to compare the null depths obtained at 30° in each case. In the equal source-strength example, the null depth observed is -32.2 dB. In the unequal source-strength example, the null depth obtained is -11.9 dB. Compensating for the -15 dB power level in the second case, the relative power level incident after adaptation is 5.3 dB higher in the second case. Of course, since this observation is limited to the center RF frequency, it is not an accurate measure of nulling degradation but, rather, an indication. As noted above, the actual nulling degradation over the frequency band of operation has been computed to be 1.5 dB.

3.1.3 Wideband Performance

Given a fixed number of adaptive weights, the adaptive nulling performance of the adaptive array system under consideration will tend to deteriorate with increased bandwidth. The fundamental cause for the degradation in this case is the fact that the channel transfer functions for incident sources will exhibit increasingly irregular characteristics due to the frequency sensitivity in the sidelobe structure of the main antenna pattern. As such, the smooth transfer function associated with an omnidirectional auxiliary antenna cannot be expected to exhibit the necessary matching for a reasonable nulling over an increasing bandwidth of operation. For this reason, a larger number of degrees of freedom than sources is necessary to provide adequate nulling performance. The degrees of freedom may be obtained in number of ports with single or multiple taps.

Of the four wideband examples presented below the first three involve ten 1-tap ports, while the fourth involves two ports with 5 taps each. It is seen that for the same number of adaptive weights, the nulling performance of the multitap approach is inferior to the single-tap multiport option. This





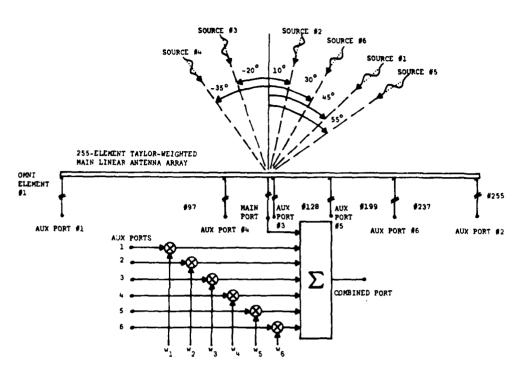


Figure 3-4. Scenario and System Definition Equal Source-Strength Example 0.1% RF Bandwidth

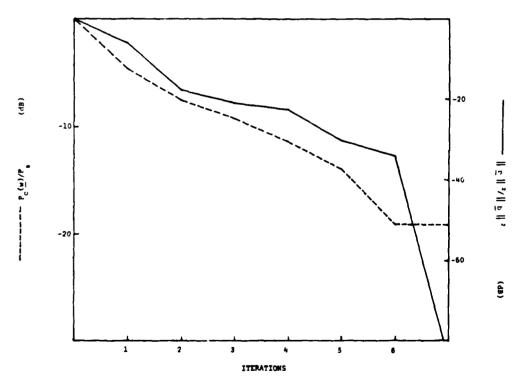


Figure 3-5. BCR Convergence Characteristics Equal Source Strength Example (See Figure 3-4)

Title Page

PROCESSING ADAPTIVE BCR

EQUAL SOURCE-STRENGTH EXAMPLE (See Figure 3-4)

6 CONTINUOUS (45°,10°,-20°,-35°,55°,30°)

SOURCES

0.1% RF BANDWIDTH

AUXILIARY PORTS

: 1/PORT TAP WEIGHTS SIMULATION BY : S. M. DANIEL & I. KERTESZ ADVANCED TECHNOLOGY AND SYSTEMS ANALYSIS MOTOROLA, INC. - GED

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Figure 3-6

Relative Signal Amplitude Before and After BCR Adaptation

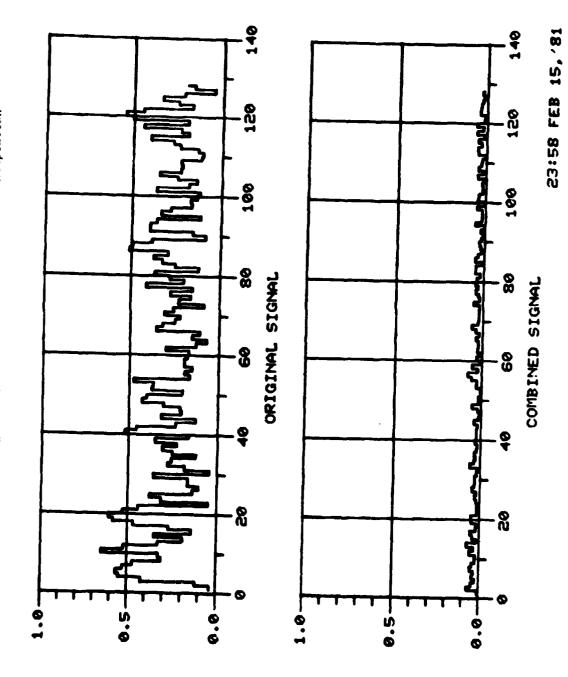
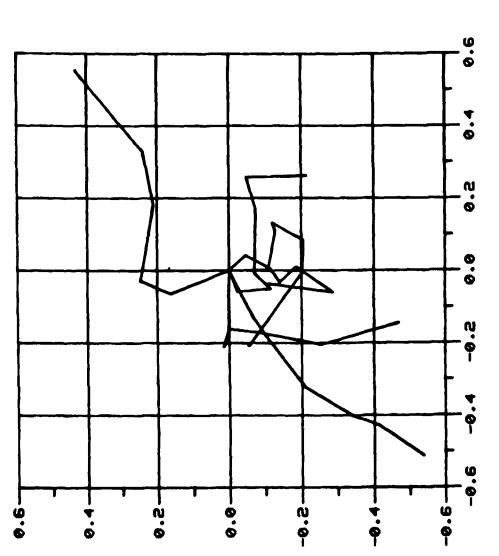


Figure 3-6 (Cont'd)

BCR Adaptive Weight Evolution in the Complex Plane

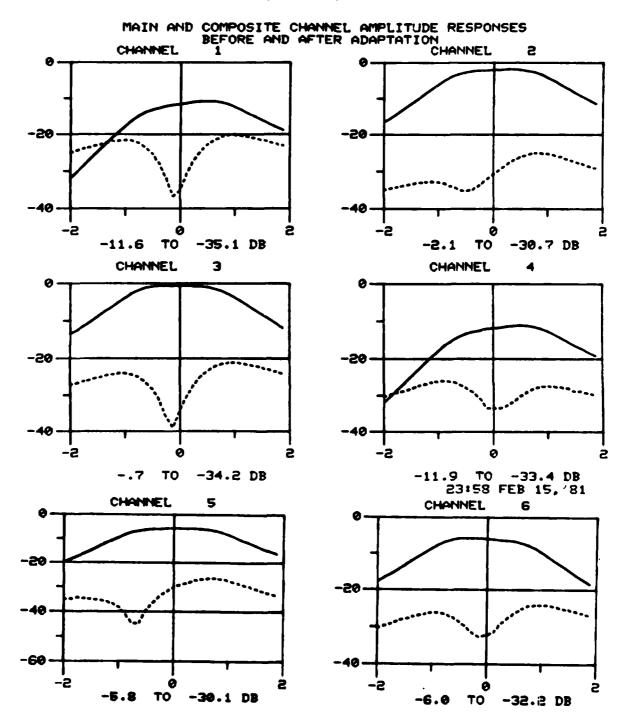


EVOLUTION OF ADAPTIVE WEIGHTS

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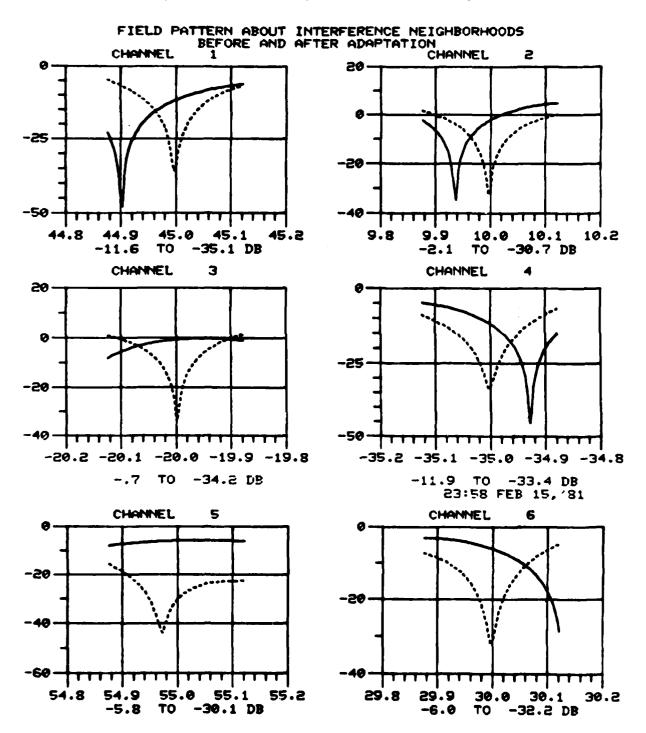
Figure 3-3 (Cont'd)

Source Transfer Function Amplitude Responses Before and After BCR Adaptation



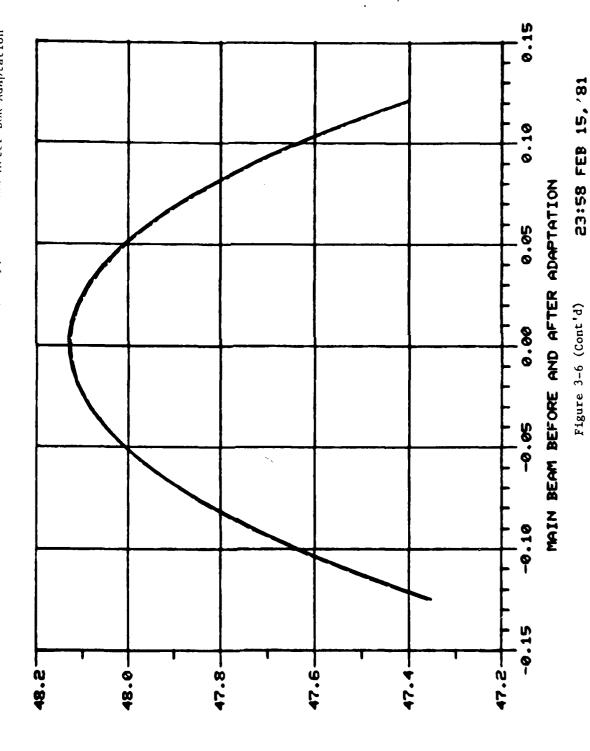
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Field Pattern Amplitudes Over 0.25 Neighborhoods About Source Angles of Arrival at RF Center



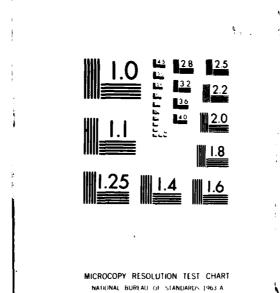
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Main Beam Field Pattern Amplitude at Center RF Frequency, Before and After BCR Adaptation



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ADAPTIVE PROCESSING BCR

UNEQUAL SOURCE-STRENGTH EXAMPLE (See Figure 3-7)

6 CONTINUOUS (0,03,-6,-9,-12,-15,dB) (-45°,10°,-20°,35°,55°,30°)

SOURCES

0.1% RF BANDWIDTH

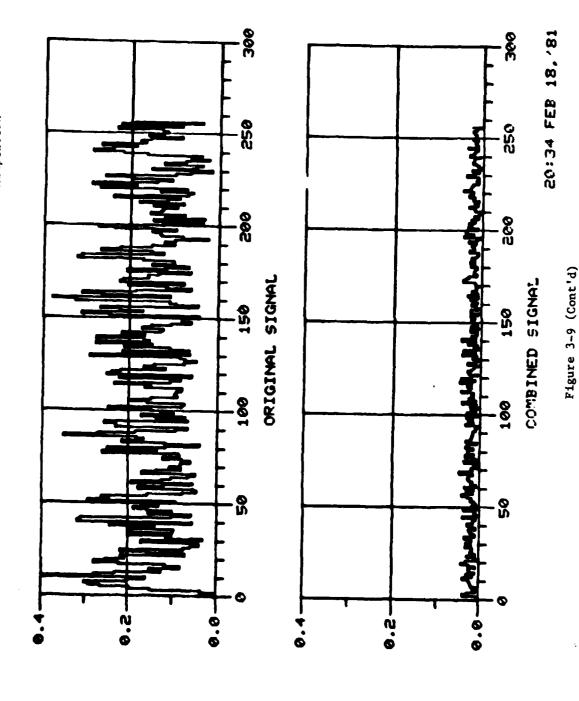
AUXILIARY PORTS

: 1/PORT TAP WEIGHTS SIMULATION BY : S. M. DANIEL & I. KERTESZ ADVANCED TECHNOLOGY AND SYSTEMS ANALYSIS MOTOROLA, INC. - GED

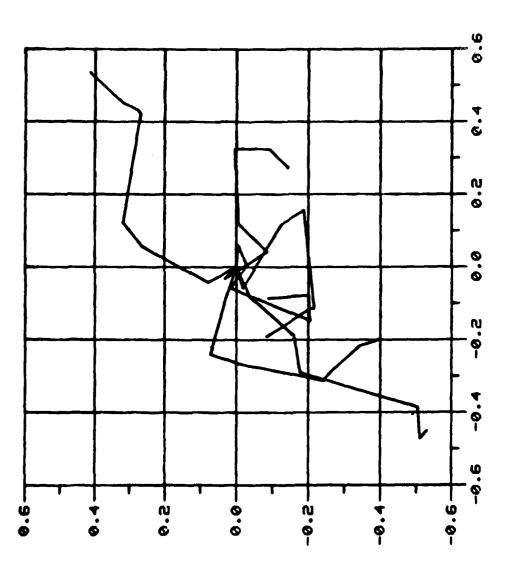
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Figure 3-9

Relative Signal Amplitude Before and After BCR Adaptation



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EVOLUTION OF ADAPTIVE WEIGHTS

Figure 3-9 (Cont'd)

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Source Transfer Function Amplitude Responses Before and After BCR Adaptation

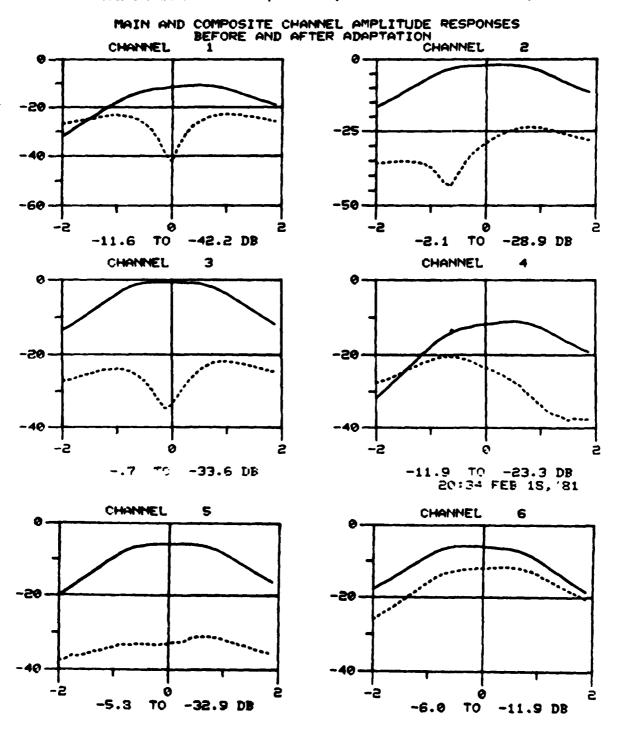
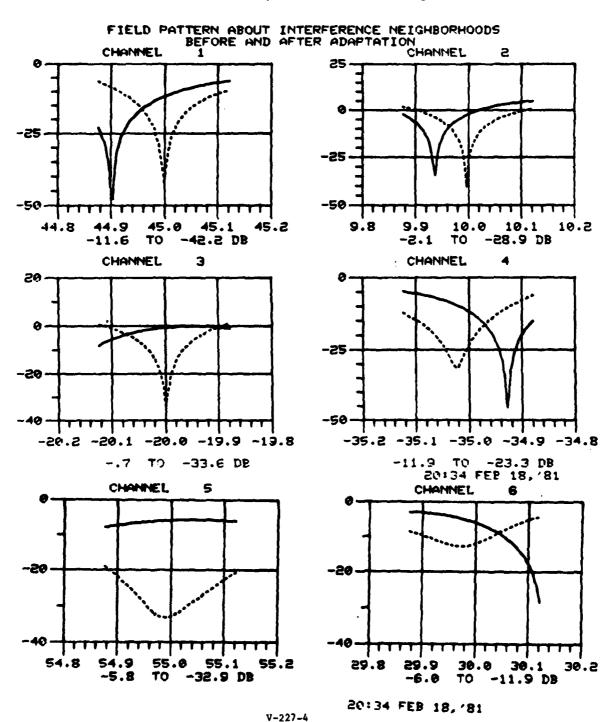


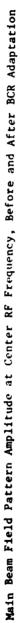
Figure 3-9 (Cont'd)

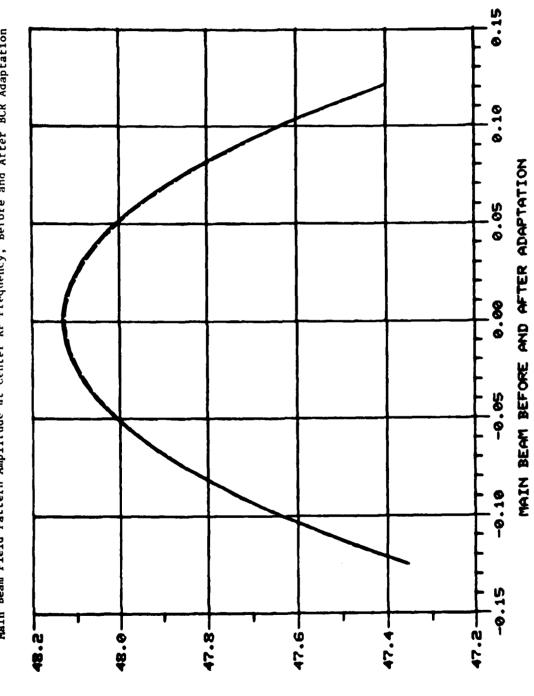
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Field Pattern Amplitudes Over 0.25 Neighborhoods About Source Angles of Arrival at RF Center



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Figure 3-9 (Cont'd)

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isolated observation, however, does not necessarily imply that multitap configurations are generally inferior. A more extensive investigation would be needed to draw a general conclusion in this regard.

3.1.3.1 One Source with 1% RF Bandwidth

Figure 3-10 gives the scenario and system description for the first wideband example. As indicated, it involves a single wideband source incident from 45° on to the adaptive array system consisting of the main linear antenna array in combination with 10 single-tap auxiliaries.

The BCR convergence behavior for this example is shown in Figure 3-11. Note that even though only a single source was involved, convergence occurred in four iterations. It appears that the relatively large RF bandwidth of 1% has given rise to a covariance matrix with rank greater or equal to 4.

Figure 3-12 is the graphical output that summarizes the BCR nulling performance for the present example. Of greatest interest here is baseband channel amplitude response before and after adaptation in Figure 3-12(d). The channel amplitude response (solid line) before adaptation is certainly not smooth. Note the sharp dip near normalized radian frequency -0.4. In combination with the 10 weighted auxiliary ports, the composite channel amplitude (dotted line) exhibits a nearly constant level ripple across the baseband.

3.1.3.2 One Source with 10% RF Bandwidth

The scenario and system description for the present example given in Figure 3-13 is identical to the previous one, except for the fact that the RF bandwidth is 10%. The convergence behavior of Figure 3-14 indicates convergence in 6 iterations, although the relative combined power has reached its minimum in the 5th iteration. As expected, the final combined power level is noticeably higher in the present wider band example than in the immediately previous case.

Figure 3-15 is the graphical output that describes the BCR nulling performance. As previously, to be noted here is the rather rough amplitude response of the baseband channel before adaptation in Figure 3-15(d). Clearly, it is considerably rougher in the present wider band case than in the previous one. The adapted composite channel is relatively smoother.

3.1.3.3 Two Sources with 2% RF Bandwidth

Figure 3-16 defines the scenario and system configuration involving two wideband sources and 10 single-tap auxiliary ports. Figure 3-17 gives the BCR convergence behavior. As shown, combined power convergence has been achieved at the 10th iteration, although it has been detected at the 11th via the relative gradient reduction below the -60 dB threshold level.

Figure 3-18 summarizes the BCR nulling performance. As before, the most interesting results here are the baseband channel amplitude response in Figure 3-18(d) associated with the transfer functions of each of the two sources before and after adaptation. As expected, the original channel amplitude response at 45° is considerably rougher than that at 10°. The adapted composite channel amplitude responses are considerably smoother.

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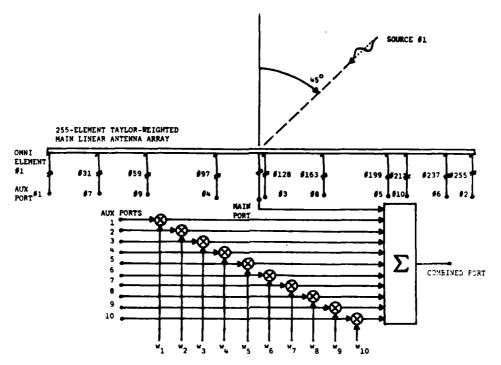


Figure 3-10. Scenario and System Description Wideband Source Example 1% RF Bandwidth

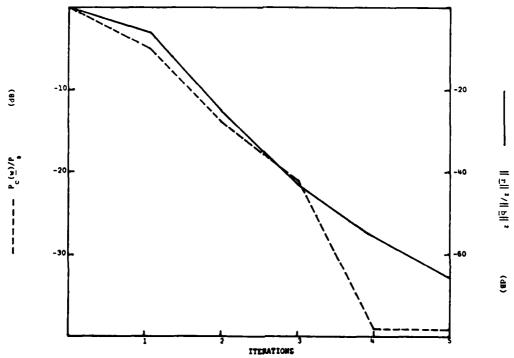


Figure 3-11. BCR Convergence Characteristics Widehead Source Example 1% RF Bendwidth (See Figure 3-10)

Title Page

BCR ADAPTIVE PROCESSING

WIDEBAND SOURCE EXAMPLE (See Figure 3-10)

SOURCES : 1 CONTINUOUS (45°)

RF BANDWIDTH : 18

AUXILIARY PORTS : 10

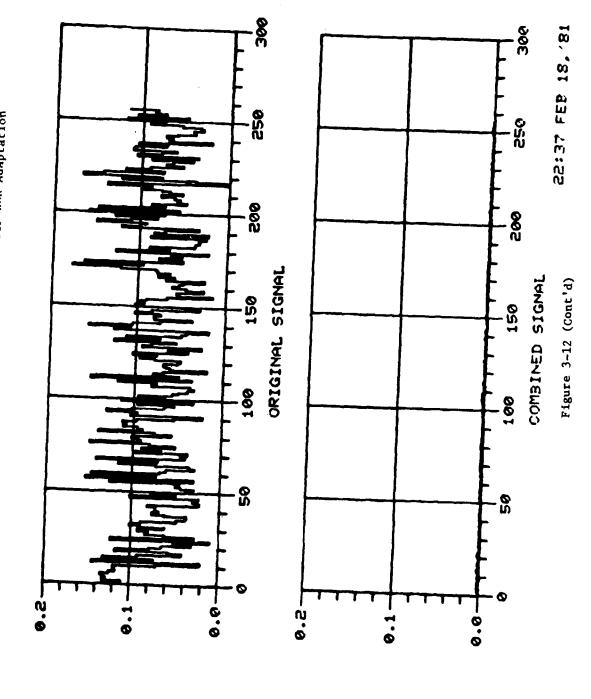
TAP WEIGHTS : 1/PORT

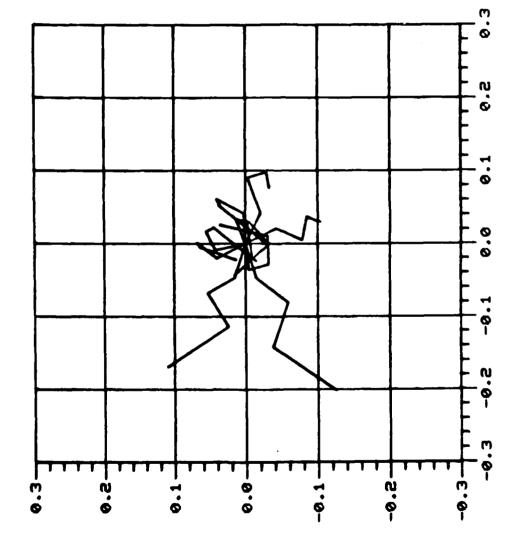
SIMULATION BY: S. M. DANIEL & I. KERTESZ ADVANCED TECHNOLOGY AND SYSTEMS ANALYSIS MOTOROLA, INC. - GED

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Figure 3-12

Relative Signal Amplitude Before and After BCR Adaptation



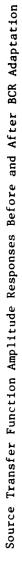


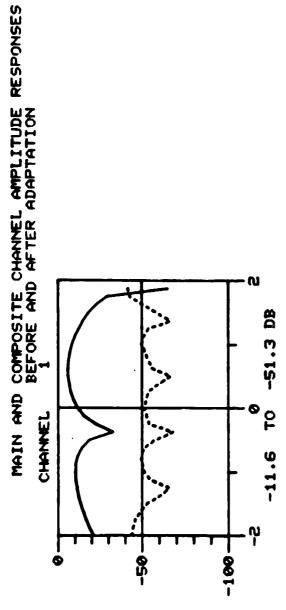
EVOLUTION OF ADAPTIVE WEIGHTS

Figure 3-12 (Cont'd)

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v-230-3





Field Pattern Amplitudes Over 0.25 Neighborhoods About Source Angles of Arrival at RF Center

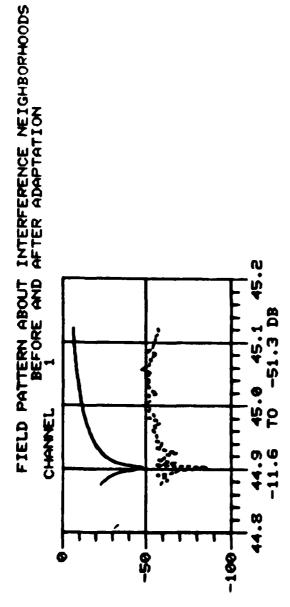
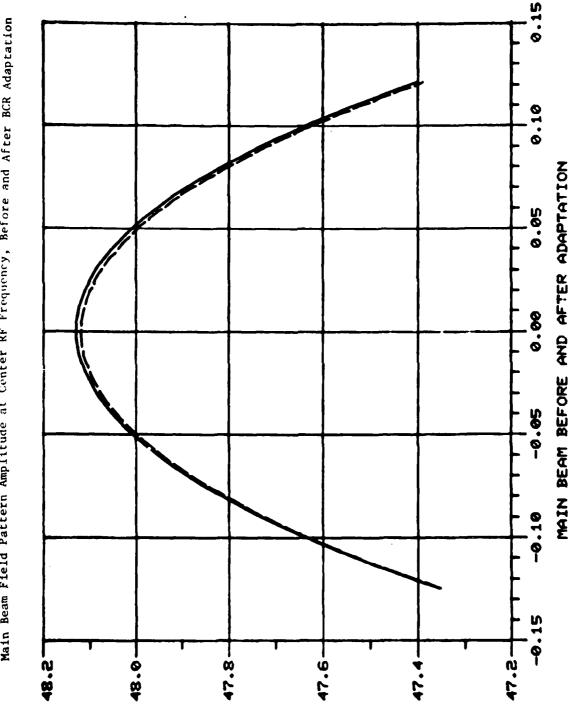


Figure 3-12 (Cont'd)

Main Beam Field Pattern Amplitude at Center RF Frequency, Before and After BCR Adaptation



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Figure 3-12 (Cont'd)

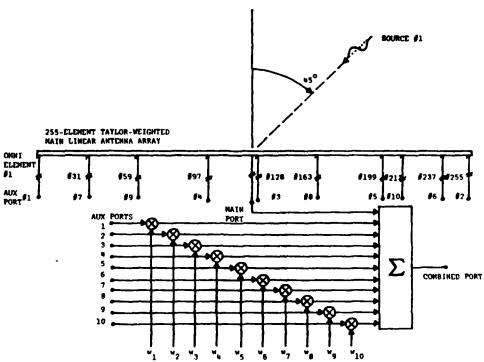


Figure 3-13. #GCR Convergence Characteristics Widebard Source Example 10% RF Bandwidth

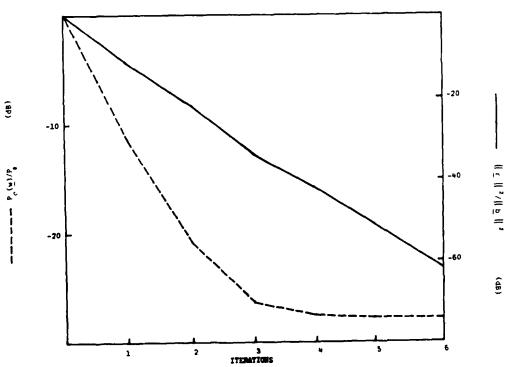


Figure 3-14. BCR Convergence Characteristics Wideband Source Dample 10% RF Bendwidth

BCR ADAPTIVE PROCESSING

WIDEBAND SOURCE EXAMPLE

(See Figure 3-13)

: 1 CONTINUOUS (45°)

SOURCES

RF BANDWIDTH : 10\$

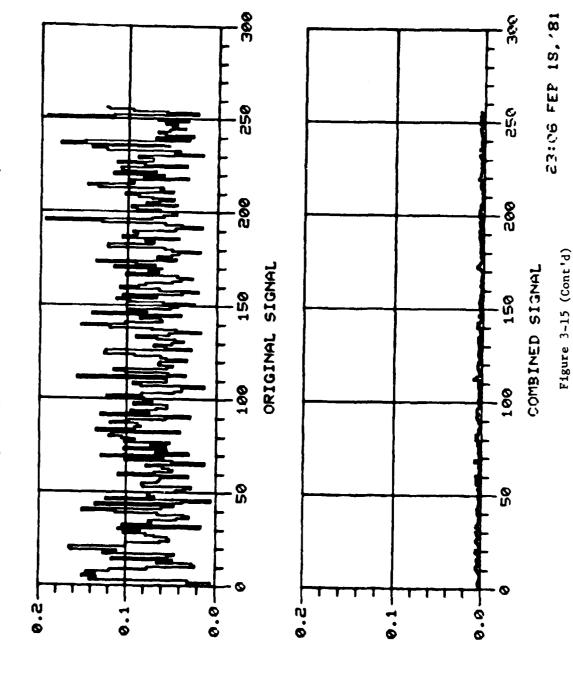
AUXILIARY PORTS : 1

TAP WEIGHTS : 1/PORT

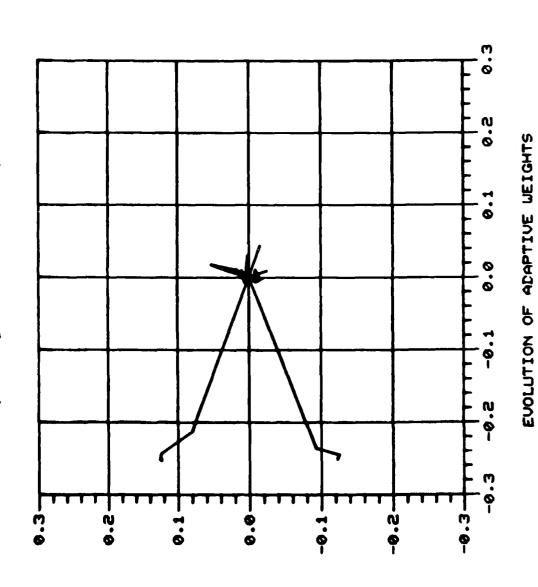
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Figure 3-15



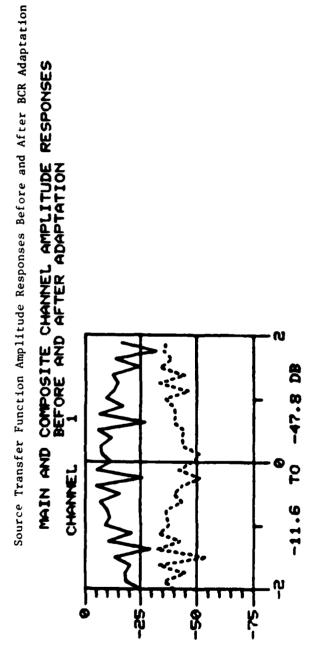
BCR Adaptive Weight Evolution in the Complex Plane



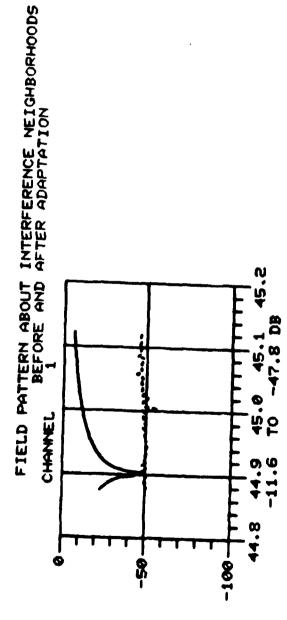
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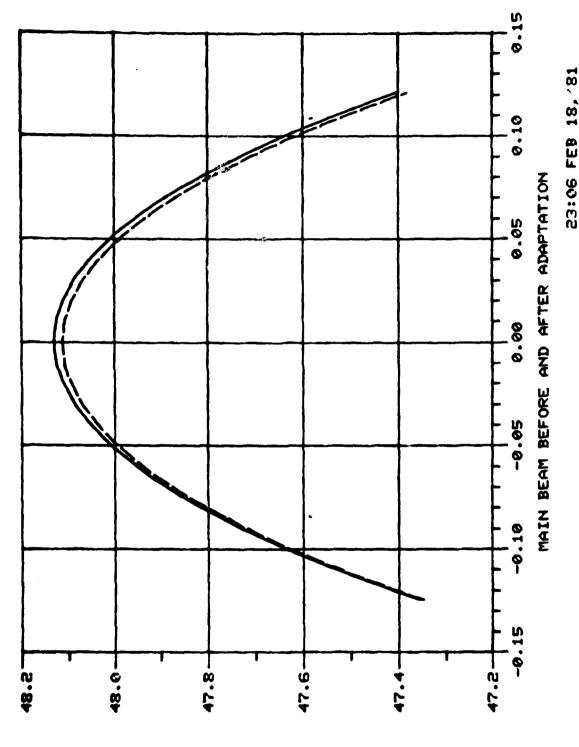
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Pield Pattern Amplitudes Over 0.25 Neighborhoods About Source Angles of Arrival at RF Center



Main Beam Field Pattern Amplitude at Center RF Frequency, Before and After BCR Adaptation



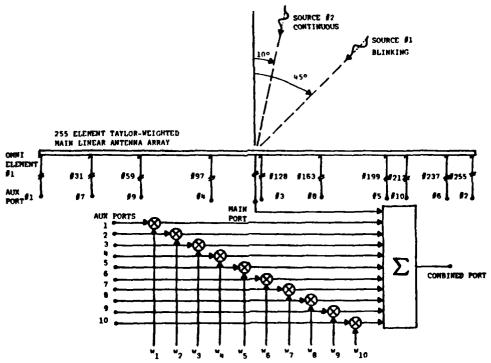


Figure 3-16. Scenario and System Description Blinking Source Example 2% RF Bandwidth

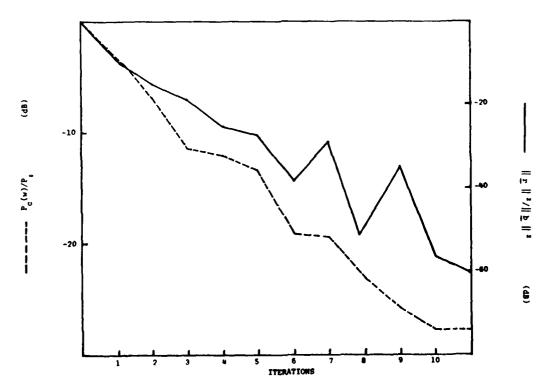


Figure 3-17. BCR Convergence Cherecteristics Wideband Source Example (See Figure 3-16)

BCR ADAPTIVE PROCESSING

WIDEBAND SOURCE EXAMPLE (See Figure 3-16)

SOURCES : 2 CONTINUOUS (45°, 10°)

RF BANDWIDTH : 2%

AUXILIARY PORTS : 10

TAP WEIGHTS : 1/PORT

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Figure 3-18

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Relative Signal Amplitude Before and After BCR Adaptation

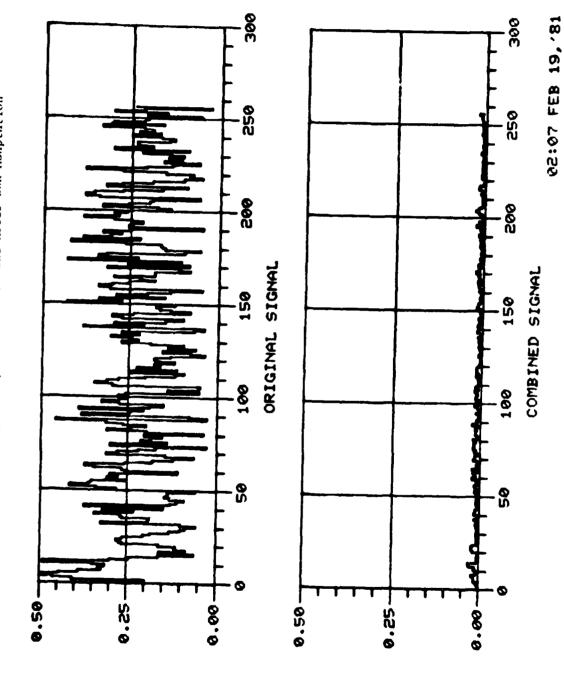


Figure 3-18 (Cont'd)

BCR Adaptive Weight Evolution in the Complex Plane

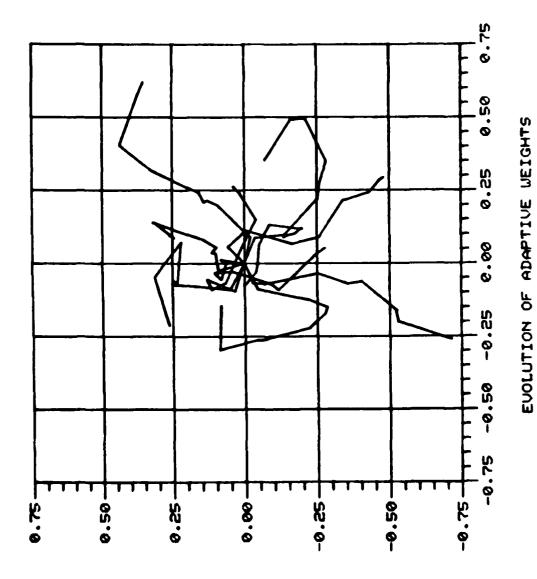
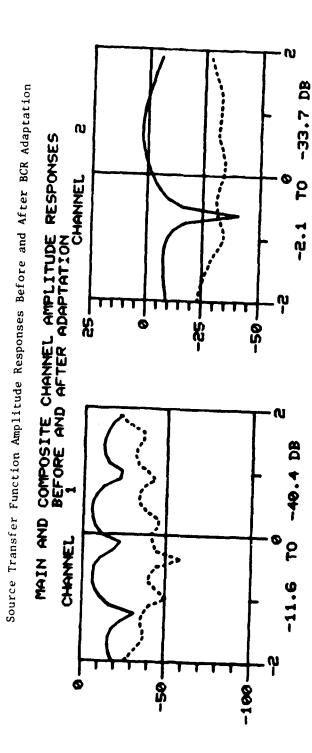


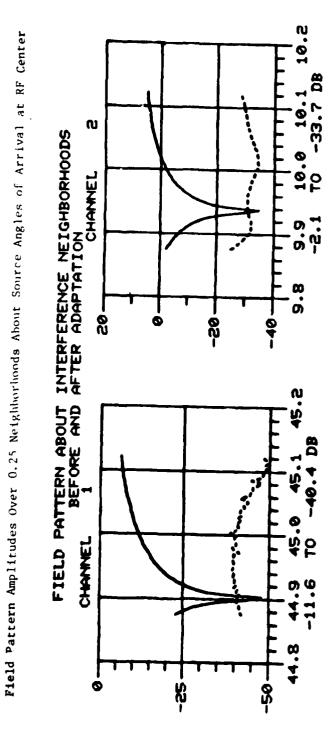
Figure 3-18 (Cont'd)

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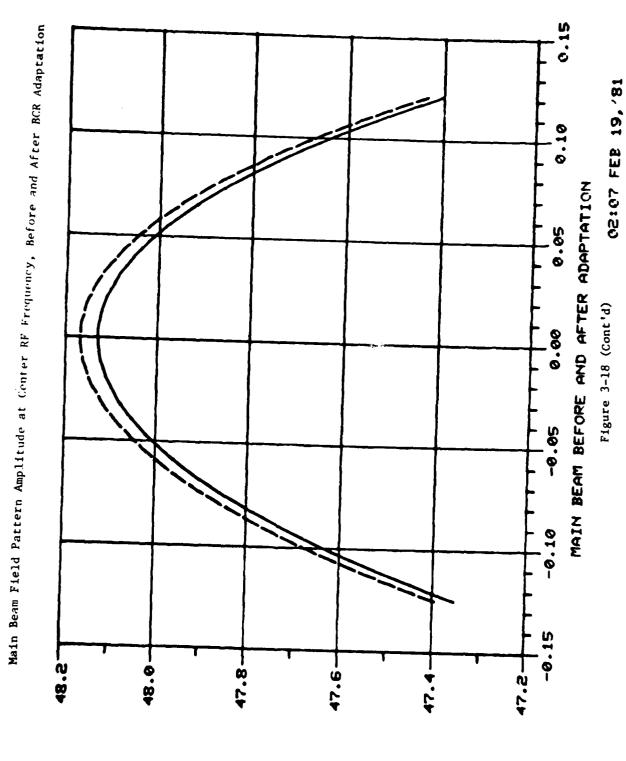




Figur. 3-18 (Cont'd)



V-234-5



V-234-6

3.1.3.4 Multitap Weighting

The previous two-source example was reconsidered with a 2-port/5-tap system configuration as shown in Figure 3-19. In an attempt to cover the antenna aperture dispersion at a 45° incidence, the unit delay D was chosen to be 0.1414 of the maximum aperture delay. Note that the five unit delays in the two auxiliary 5-tap delay lines are accompanied with 2.5D of delay in the main antenna for the purpose of providing proper delay balance.

Figure 3-20 shows the BCR convergence behavior for the present example. Note that, although convergence has been indicated at the 12th iteration, no more than 1 dB additional combined power suppression was achieved beyond the 4th.

Figure 3-21 summarizes the BCR adaptive nulling performance. Clearly manifested in the adapted channel amplitude responses of Figure 3-21(d) is the poor nulling performance that has been achieved.

The results in this example appear to imply that, given a fixed number of adaptive weights, they will be most effective as single taps over the same number of ports rather than multiple taps over an appropriately reduced number of ports. The observed relative combined power suppression of -9.6 dB was improved to only -10.6 when the number of taps was doubled to 10 per port and spaced D/2 apart. Of course, further investigation is necessary in order to substantiate or refute the validity of this observation in general. It would be appropriate, in such an investigation, to evaluate the usefulness of non-uniform tap-delay spacing, varying the extent of each delay line and increasing the number of multitap ports.

3.1.4 Multipath Examples

The two examples included here are two extreme cases of the multipath phenomenon. Both examples involve six multipaths from a given source, consisting of a direct path at 45° and five indirect paths at 0.05° intervals beyond 45°, with equal signal strengths. The bandwidth is chosen to be 0.1% and six 1-tap ports are used.

The first example addresses a case where the six paths are highly correlated. As such, the channel delays chosen are 0.00, 0.05, ..., 0.25 of a sample-time interval ΔT , respectively, where, in the present simulation, ΔT is half of the Nyquist-rate interval. Figure 3-22 shows the scenario and system description for this example. Figure 3-23 gives the observed BCR convergence characteristics. The overall BCR performance is summarized in graphical output presented in Figure 3-24. The most interesting feature to be noted here is the collection of field patterns in Figure 3-24(e). Indeed, the high correlation among the six multipath signals has given rise to a narrow composite pattern null, apparently, at the "centroid" of the six signal paths. Another outcome of the high correlation among the multipath signals is the excellent nulling performance observed.

In an attempt to evaluate the extreme case of highly uncorrelated multipath signals, each signal was generated from an independent noise source. Figure 3-25 shows the scenario and system description for this case. Figure 3-26 contains the observed BCR convergence characteristics. Figure 3-27 is the graphical output obtained in this case.



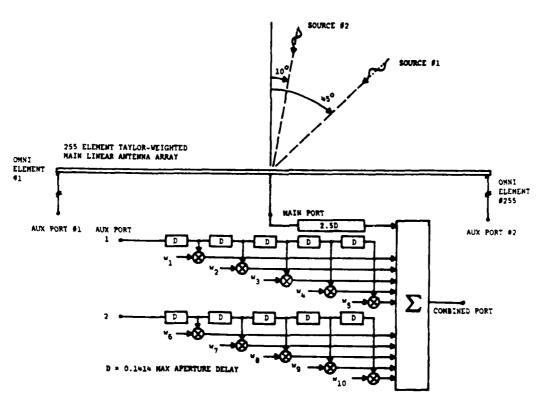


Figure 3-19. Scenario and System Description Two Wideband Sources/Two 5-Tap Ports 2% RF Bandwidth

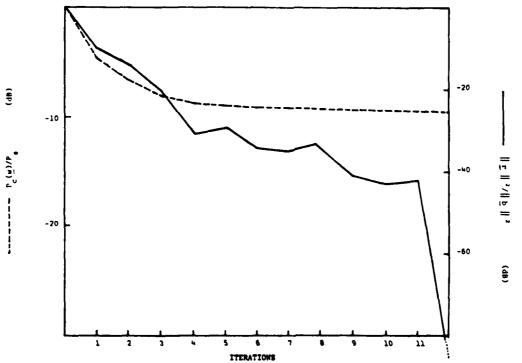


Figure 3-20. BCR Convergence Characteristics Videbend Source Example 0.2% RF Bendwidth (See Figure 3-19)

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ADAPTIVE PROCESSING

WIDEBAND SOURCE EXAMPLE (See Figure 3-19)

2 CONTINUOUS (45°, 10°)

2%

SOURCES

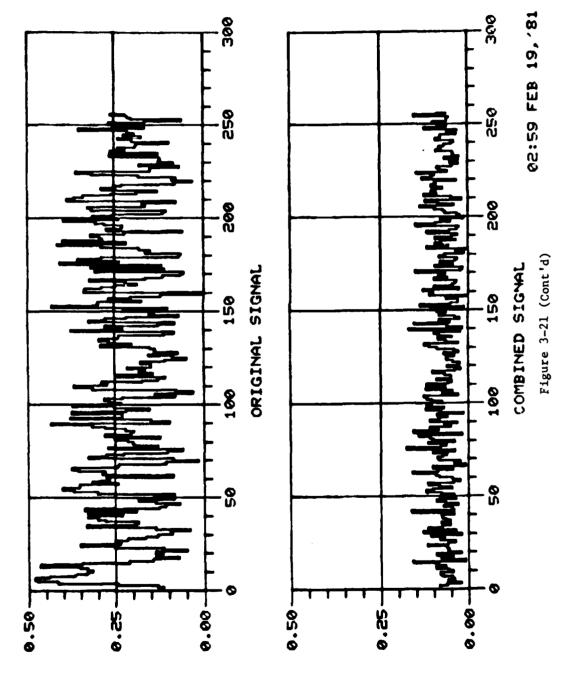
AUXILIARY PORTS RF BANDWIDTH

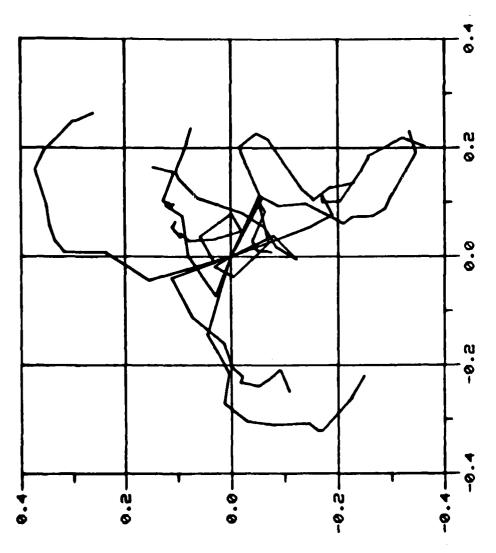
5/PORT TAP WEIGHTS S. M. DANIEL & I. KERTESZ ADVANCED TECHNOLOGY AND SYSTEMS ANALYSIS MOTOROLA, INC. - GED SIMULATION BY :

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Figure 3-21

Relative Signal Amplitude Before and After BCR Adaptation





EUOLUTION OF ADAPTIVE WEIGHTS

Figure 3-21 (Cont'd)

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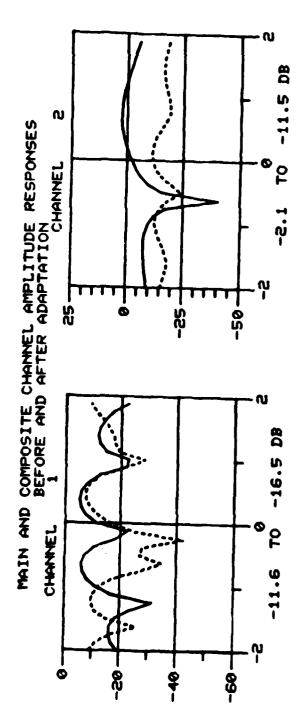
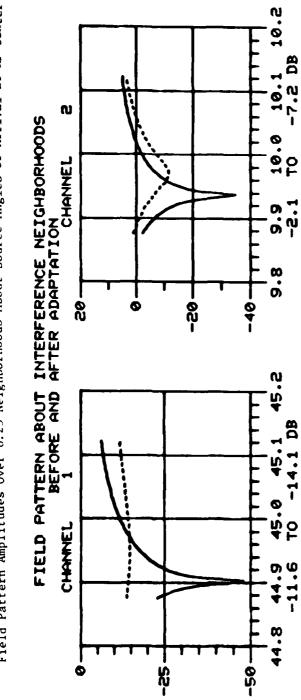


Figure 3-21 (Cont'd)

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Field Pattern Amplitudes Over 0.25 Neighborhoods About Source Angles of Arrival at RF Center



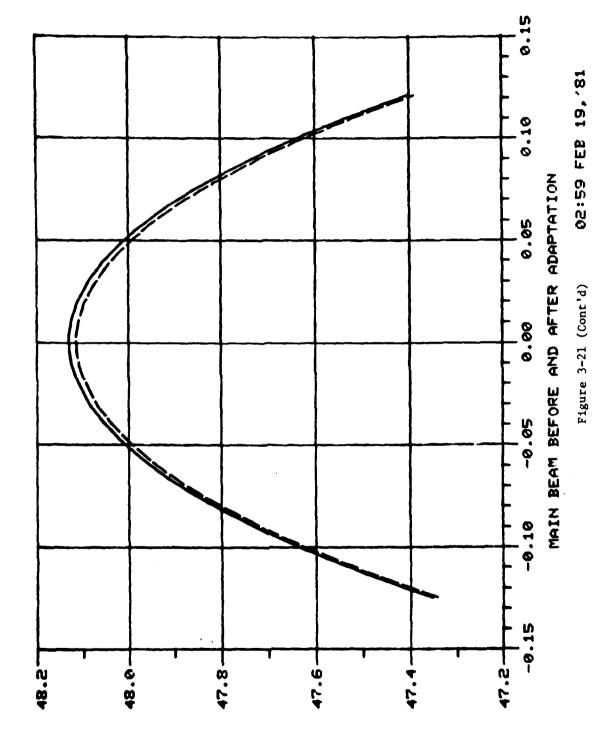
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Figure 3-21 (Cont'd)

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Main Beam Field Pattern Amplitude at Center RF Frequency, Before and After BCR Adaptation

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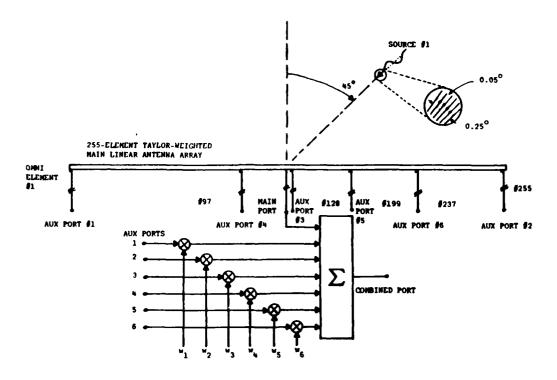


Figure 3-22. Scenario and System Description Multipath Example Highly Correlated Case 0.1% RF Bandwidth

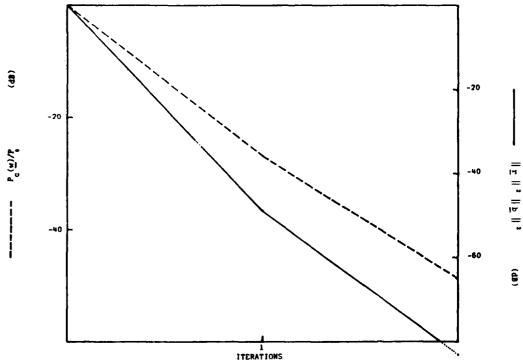


Figure 3-23. BCR Convergence Characteristics Hultipath Example (See Figure 3-22)

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ADAPTIVE PROCESSING RCR R

MULTIPATH EXAMPLE (See Figure 3-22) (Highly Correlated Multipath Signals)

SOURCES

6 CONTINUOUS MULTIPATHS (45.0°, 45.05°, ..., 45.25°) (0.00ΔT, 0.05ΔT, ..., 0.25ΔT)

0.1% RF BANDWIDTH

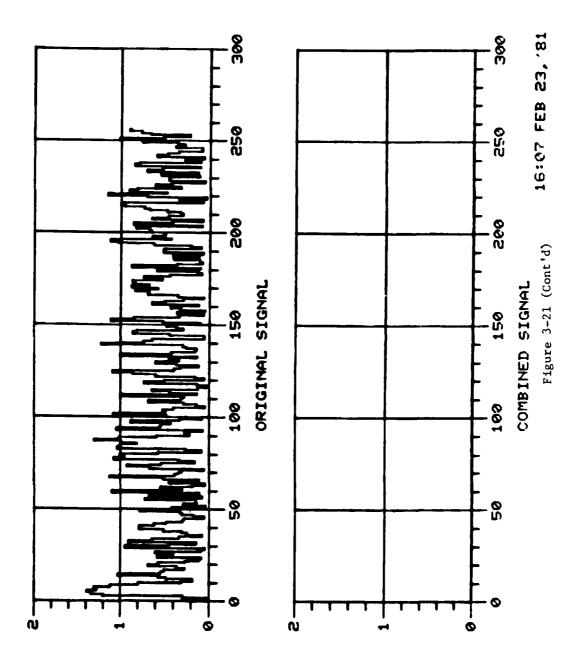
AUXILIARY PORTS

1/PORT TAP WEIGHTS

SIMULATION BY : S. M. DANIEL & I. KERTESZ ADVANCED TECHNOLOGY AND SYSTEMS ANALYSIS MOTOROLA, INC. - GED

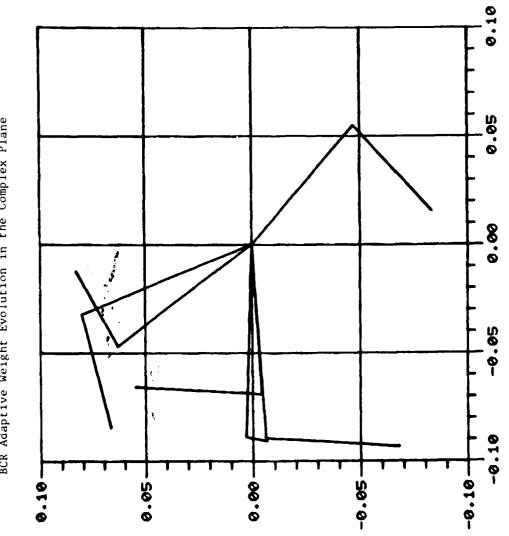
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Figure 3-21



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EVOLUTION OF ADAPTIVE WEIGHTS

Figure 3-21 (Cont'd)

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Source Transfer Function Amplitude Responses Before and After BCR Adaptation

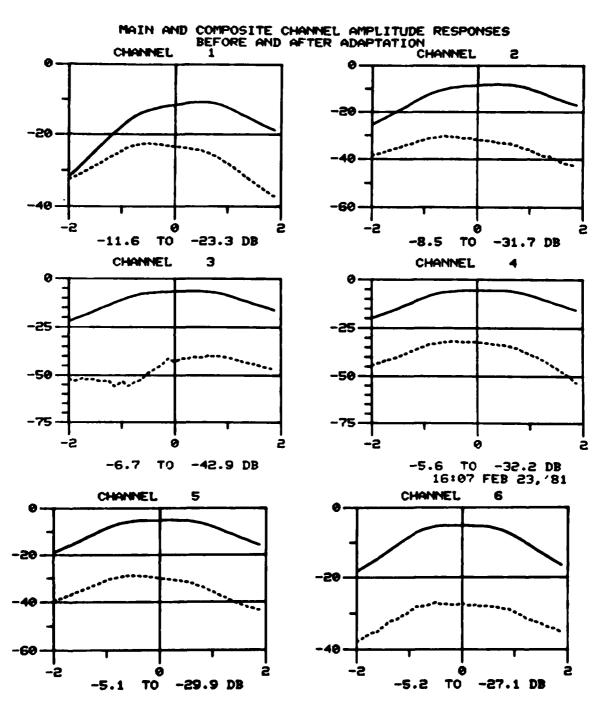
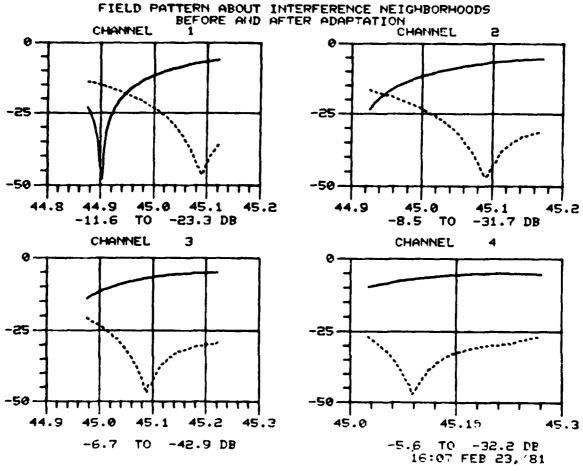


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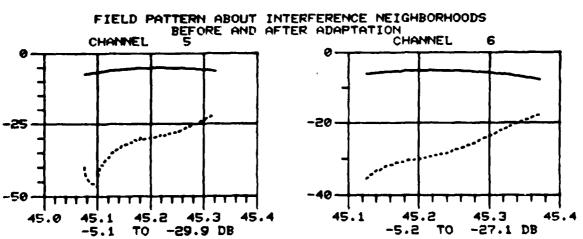
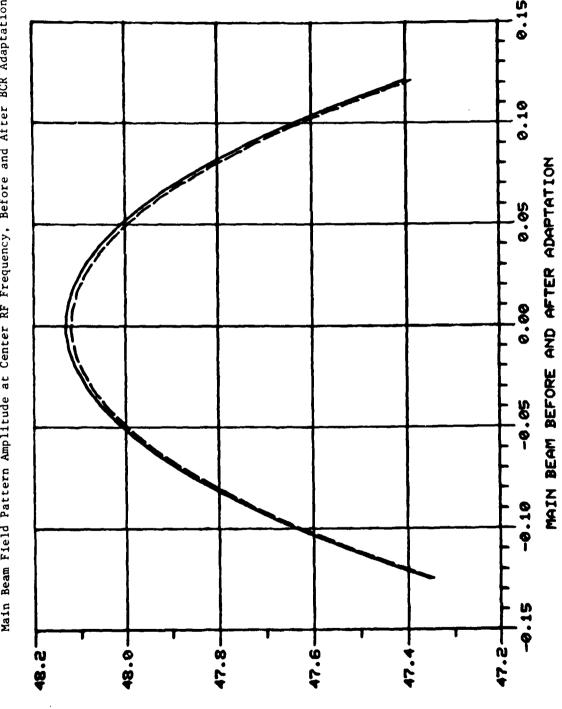


Figure 3-21 (Cont'd)

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Figure 3-21 (Cont'd)

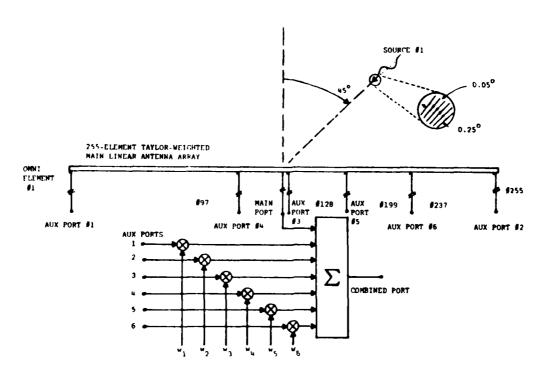
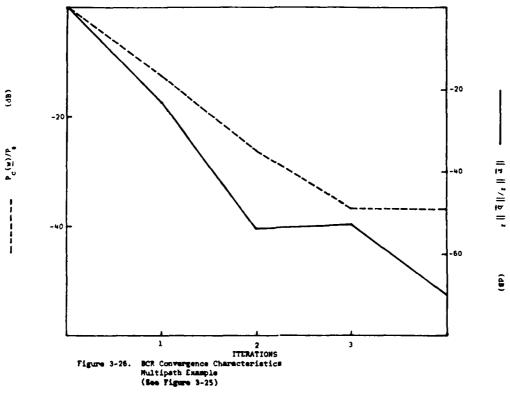


Figure 3-25. Scenario and System Description Multipath Example Uncorrelated Case 0.1% RF Bandwidth



Section of the Section Section

1

ADAPTIVE PROCESSING RCR

MULTIPATH EXAMPLE (See Figure 3-25)

(UNCORRELATED MULTIPATH SIGNALS)

6 CONTINUOUS (45.00°, 45.05°, ..., 45.25°) SOURCES

RF BANDWIDTH PORTS

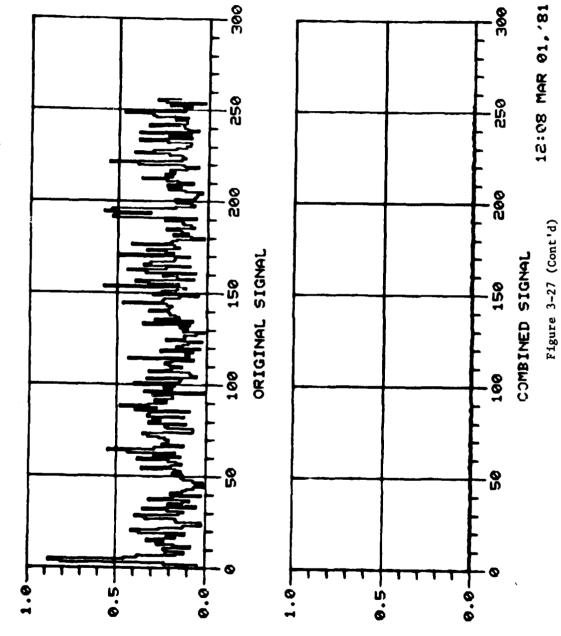
1/PORT TAP WEIGHTS S. M. DANIEL & I. KERTESZ ADVANCED TECHNOLOGY AND SYSTEMS ANALYSIS MOTOROLA, INC. - GED SIMULATION BY :

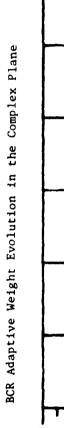
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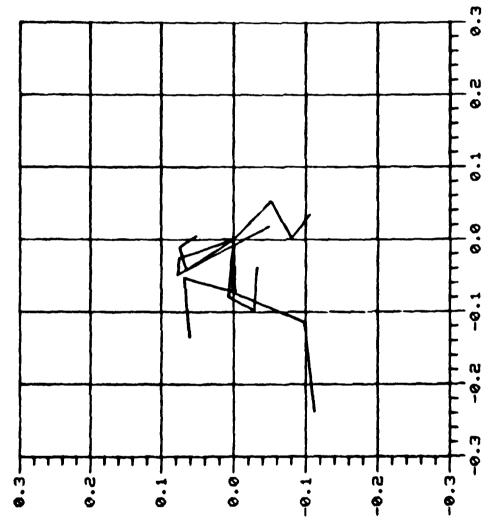
Figure 3-27

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Relative Signal Amplitude Before and After BCR Adaptation







EVOLUTION OF ADAPTIVE WEIGHTS

12:08 MAR 01, '81 Figure 3-27 (Cont'd)

Source Transfer Function Amplitude Responses Before and After BCR Adaptation

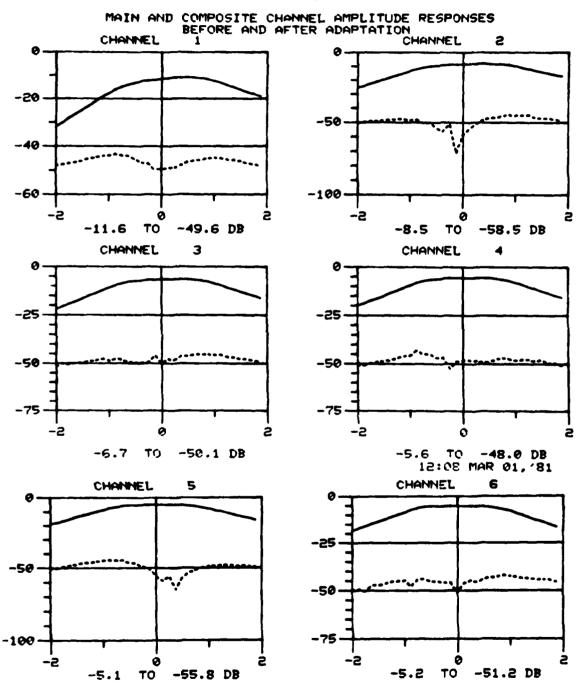
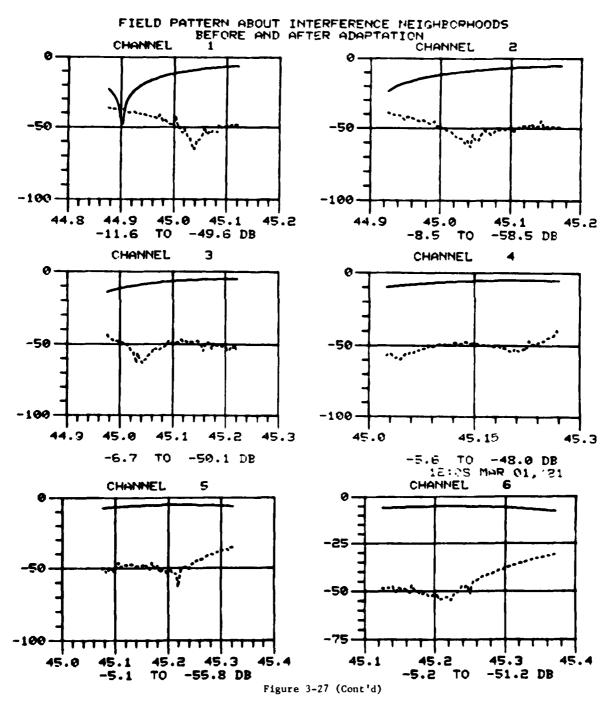


Figure 3-27 (Cont'd) 12:08 MAR 01, '81

Field Pattern Amplitudes Over 0.25 Neighborhoods About Source Angles of Arrival at RF Center



V-241 4 12:08 MAP 01, '81

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Main Beam Field Pattern Amplitude at Center RF Frequency, Before and After BCR Adaptation MAIN BEAM BEFORE AND AFTER ADAPTATION 9.02 0.00 -0.05 -0.10 47.8-47.2-47.6-48.2 48.0

12:08 MAR 01, '81

Figure 3-27 (Cont'd)

To be noted here is the relatively degraded nulling performance and the wide pattern nulls in comparison to the previous example. Since the multipath signals in latter example are uncorrelated, these observations are as expected.

3.2 General Results

The BCR simulation results presented in the previous section relate to specific single examples. In contrast, the general results included in this section deal with the BCR nulling performance as a function of various pertinent scenario and system parameters.

3.2.1 BCR Convergence Characteristics

Figure 3-28 attempts to demonstrate BCR convergence characteristics as a function of a number of incident sources. The scenario and system description is as shown in the Figure. Operating at a 0.1% RF bandwidth, the adaptive array system of a main linear antenna array and six omnidirectional auxiliaries is exposed to incident wideband noise sources ranging from one to six. Using a single adaptive weight per auxiliary port, Figure 3-28 gives the relative combined power and relative gradient metric at each BCR iteration for each choice of number of incident sources, indicated next to each set of two curves.

One overall prominent feature that may be observed in Figure 3-28 is the decrease in nulling performance with an increase in the number of sources. In fact, the relative combined power curves exhibit a monotonic upward trend with increased number of sources. The same behavior does not seem to predominate with respect to the relative gradient metric curves.

Two specific local features are of interest here. First, note that in every case at least one extra iteration was necessary to achieve convergence. This is due to the fact that even with the moderate 0.1% RF bandwidth, the rank of the covariance matrix over the six auxiliary port signals exceeded the actual number of incident sources by at least one. Recall that in the wideband examples discussed in the previous section, the apparent rank of the covariance matrix was well in excess of the one or two sources considered, as evidenced by the number of BCR iterations used.

The other prominent local feature is the nonmonatonic behavior of the relative gradient metric. In particular, note that, in the case involving five incident sources, there is a pronounced increase in relative gradient metric at the sixth iteration. This behavior is not unusual in the underlying CG algorithm employed. What is important here is that while the gradient metric has increased, the relative combined power has decreased.

3.2.2 RF Bandwidth Dependence

The state of the s

Figure 3-29 shows the dependence of BCR nulling performance for a 10-port 1-tap/port system as a function of % RF bandwidth for two cases of one and six incident sources.

In the case of six incident sources the degradation in nulling performance with increased %RF bandwidth is quite rapid. As expected, however, the nulling performance is rather respectable even up to 10% RF bandwidth. The rather irregular behavior over the 0-1% RF bandwidth region is not fully clear at this time. Perhaps it is related to the blind region phenomenon described next.

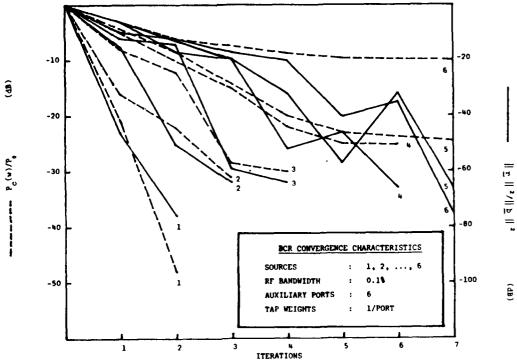


Figure 3-28. BCR Convergence Characteristics as a Function of Number of Incident Sources

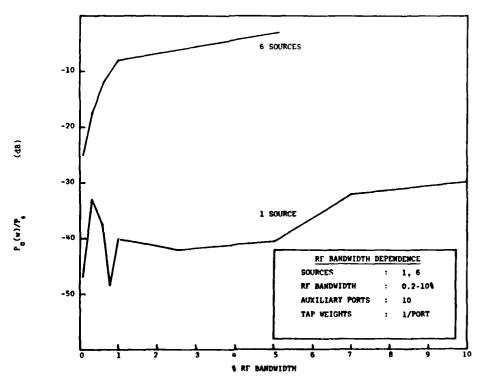


Figure 3-29. BCR Adaptive Hulling Performance as a Function of \$ RF Bandwidth

3.2.3 Elind Region Phenomenon

A phenomenon which often plagues adaptive nulling performance is the blind region phenomenon which refers to poor nulling performance over specific angular regions in the composite field pattern. As such, it may be encountered in adaptive E-scan systems. This phenomenon may be subdued substantially by adding more degrees of freedom, in the form of adaptive weights, either as additional taps in existing ports or single taps over additional corresponding ports.

Figure 3-30 demonstrates the blind region phenomenon for an adaptive array system characterized by a 0.1% RF bandwidth and six 1-tap auxiliary ports for four scenarios involving 3, 4, 5 and 6 incident sources.

Of the four cases shown, the 6-source case gives rise to the most prominent blind region occurrence. Note, the relatively poor adaptive nulling performance over a nearly 0.8° "blind region" of the total 1.4° degrees scanned. The blind region in the 5-source case occupies a substantially smaller angular fraction. The indicated blind region in the 4-source case is rather shallow. No blind region is indicated in the 3-source case. Clearly, with additional single-tap ports, the blind region problem may be substantially minimized.

3.2.4 Multitap Weighting

Given an adaptive array system with a fixed number of auxiliary ports, its nulling performance may be gradually improved by appropriately introducing additional delaying tap weights at each port. The two examples included below demonstrate the nulling effectiveness of multitap weighting in a large bandwidth case and in a case involving a blind region.

The first example involves one incident source, a 10% RF bandwidth and one auxiliary port. Figure 3-31 shows the BCR adaptive nulling performance as a function of the number of tap weights, $N_{\rm T}$, spaced uniformly over a delay equivalent to that of the full aperture of the main antenna array. To be noted here is an overall improvement trend with increased number of taps, although not monotonic. A satisfactory explanation of this behavior will have to await further specific investigation.

The second example considered involves three incident sources, a 0.1% bandwidth and three auxiliary ports. Figure 3-32 shows the BCR nulling performance as a function of aximuth scan shift for one and two tap weights per port. Note that the major blind region has remained practically intact in going from one to two taps. The obvious question at this point is whether additional taps could in fact diminish the blind region in any substantial way. An important observation here is that if the adaptive weights were applied over four different ports, then the blind region would, in fact, decrease substantially.

Here, the blind region was arbitrarily defined to be that region over which the residual combined power is at least 6 dB higher than that of its minimum value over the scanned angular region. This, of course, is not a strict rule but it does permit a qualitative valuation in the present discussion.

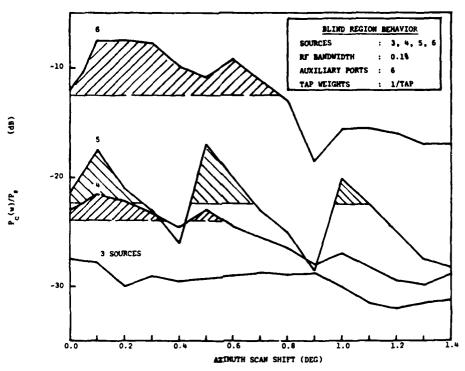


Figure 3-30. Blind Region Behavior as a Function of Number Of Sources

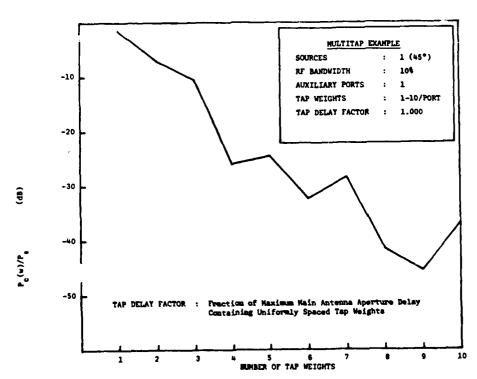


Figure 3-31. BCR Adaptive Hulling Performance as a Function of Humber of Tap Weight

Stall another indication that taps and ports are not interchangeable is seen in Table 3-4 which presents adaptive nulling performance of two single sources with two numbers of 1-tap ports, two numbers of taps over a single port with two associated tap delay factors.

To be noted immediately is the respectable performance of the two single-tap multiport cases. What is quite unexpected is the inconsistent nulling performance in the single-port multi-tap cases. For example, the 10-tap case with a tap delay factor of 1.000 yields a satisfactory performance in the presence of the 7° source but does rather poorly against the 45° source. Using a delay factor of 0.707, the performance quality is reversed for each of the separate sources. Increasing the number of taps to 20 and using a tap delay factor of 1.000 gave rise to a marginal performance against either source, each one worse than the previous best performance of -17.95 and -22.03. Clearly, increasing the number of taps did not improve the nulling performance. Using 20 taps with a tap delay factor of 0.707, however, has given the best nulling performance against each separate source.

Even though the last line in Table 3-4 of results might suggest an equivalence between taps and ports, the previous three lines provide evidence to the contrary. In fact, the additional results in Section 3.1.3.4 add to this evidence. Certainly, a more substantial investigation must be conducted before any general conclusions may be made in connection with the observation made here.

3.2.5 Receiver Mismatch

In all cases considered so far, the main and auxiliary receivers have been assumed to be perfectly matched. Specifically, the receiver transfer function has been assumed to be the baseband equivalent of a two-pole Butterworth 10% bandwidth IF filter. Since perfect matching among filters is not practically possible, it is desirable to determine the effect of their mismatch on nulling performance and thus establish design tolerances necessary for a given application.

Figure 3-33 demonstrates the dependence of nulling performance on receiver mismatch. The case considered involves three sources, a 0.1% RF bandwidth, three ports with two-pole Butterworth or six-pole Chebyshev IF filters. One and two-tap implementations are evaluated.

The particular mismatch on the receivers is in the form of a simultaneous percentage bandwidth reduction and center frequency offset. More specifically, each auxiliary receiver is assigned a mismatch level ranging from zero (perfect match with the main receiver) to a certain percent bandwidth tolerance level. In the present case, the first auxiliary receiver is matched to the main, the second is mismatched by half the tolerance level and the third is mismatched by the full percent bandwidth tolerance indicated in Figure 3-33.

As expected, the nulling performance is more sensitive in the case of the more selective six-pole Chebyshev filter than that of the two-pole Butterworth. Note that to achieve -20 dB of nulling, a 4% tolerance is required of the six-pole filter while as much a 15% is allowed for the two-pole.

Table 3-4. Multiport/Multitap Comparison

	i	SCENARIO AND S	YSTEM DESCRIPTION		
SINGLE SOURCE AT : 7° or 45° RF BANTWIDTH : 10% NUMBER OF ONE-TAP PORTS : 10 or 20 NUMBER OF TAPS ON SINGLE PORT : 10 or 20					
NUMBER DE PORTS	TAPS PER PORT	TAP DELAY FACTOR	RELATIVE COMBINED POWER LEVEL (dB) FOR EACH OF TWO SEPARATE SOURCES		
	1		AT 7°	AT 45°	
13	1		-36.34	-30.00	
20	1 1			-29.36	
1	10	1.000	-17.35	- 2.25	
1	10	0.707	- 1.38	-22.03	
1	20	1.000	-10-12	-13.51	
1	20	0.707	-47.01	-31.66	

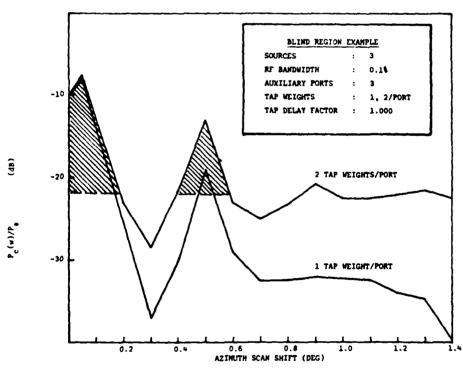


Figure 3-32. Blind Region Schevior as a Function of Number of Tap Weights

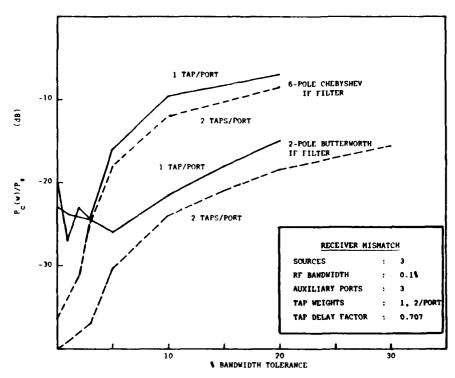


Figure 3-33. BCR Adaptive Mulling Performance as a Function of Bandwidth Tolerance for Two Different IF Filters

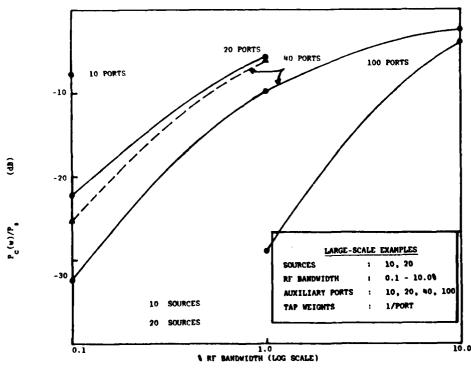


Figure 3-34. BCR Large-Scale Performance

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Using 2 taps per port it is possible to achieve a certain amount of equalization between receivers which is manifested in improved nulling performance for both receiver designs. As such, by introducing two taps per port, the bandwidth tolerances of the 6-pole and 2-pole filter designs may be increased to 5% and 20%, respectively, in order to achieve -20 dB of nulling. Of course, design tolerances must be much lower than these if one is interested in minimizing the loss in potential nulling performance.

3.2.6 Large-Scale Performance

A number of large scale BCR simulation examples were run involving 10 and 20 sources. Relative combined power results after BCR adaptation have been combined into Figure 3-34 to demonstrate, graphically, general performance trends with various scenario and system parameters.

For the 10-source case, the adapted relative combined power level has been plotted against a log-scaled % RF bandwidth for 10, 20, 40 and 100 ports. For the 20-source case, only 40 ports were used. Even though the number of actual data points was small in each instance, curves have been drawn to enhance the visibility of the individual results. The nulling performance improvement against 10 sources in going from 10 to 20 to 40 and finally to 100 single-tap ports is clearly suggested.

It should be mentioned that the main antenna aperture used in these large-scale examples was 4-times that of all previous examples. In all previous examples a 255-element main antenna array was used; a 1001-element array was used here. As such, the sidelobe sensitivity to frequency over the specified bandwidth must be 4-times that encountered in the previous examples. For this reason, the results shown in Figure 3-34 would be substantially improved if the 255-element main antenna array were used.

3.3 Comments on BCR Variations

The BCR simulation program, BCRS, employed the conventional form of the CG algorithm presented in Theorem 3-9 of Project Memorandum 8512-03. For purposes of minimizing the roundoff error, the alternate CG form stated in Theorem 3-11 could have been used. During the early stages of program development, the latter formulation was compared to the former, but no significant numerical improvement was noted. A further investigation would certainly be needed before the preferred form of the CG algorithm could be identified for the present application. The numerical advantage of the alternate CG form could certainly be exploited in a reduced numerical resolution environment of a digital implementation.

The constrained BCR formulation developed in Project Memorandum 8512-03 was considered in the simulation of the adaptive array system in question. Based on the minimal effect observed on the main beam after constrained BCR adaptation, it did not make sense to switch to a constrained BCR simulation. Of course, the CBCR approach would be imperative for a fully adaptive array or adaptive beamforming system.

In an attempt to minimize the roundoff error in the BCR process, especially in large-scale examples, the CG algorithm may be repeated using the final estimate of the previous execution as the initial estimate of the second. This was discussed in Project Memorandum 8512-03. To minimize the

total running time of this two-stage process it was decided to investigate a scheme for substantially decreasing the computational time during the first stage. The covariance matrix involved was approximated by a limited band about the main diagonal, while all entries beyond this region were assumed to be zero. By the very nature of the underlying CG algorithm, all computations involving the zero entries in the covariance matrix could be literally skipped.

When this Band-Diagonal BCR (BDBCR) approach was attempted with various choices of band-size, it was discovered that the resulting adaptive weight vector estimate was rather poor. Also, when this estimate was used as an initial estimate for the second BCR stage, it did not yield an estimate that was any better thar could be obtained via one normal BCR execution. Further, in cases where the rank of the covariance matrix was significantly less than the system dimensionality, the BDBCR approach took many more iterations to converge than the normal BCR process. As such, the anticipated computational saving was nearly eliminated in many cases. A more dedicated study would be necessary to establish the usefulness of the BDBCR approach for the current application. For the time being, it appears that the roundoff on a BCR estimate may be minimized by allowing a small number of additional iterations or limiting a second stage of processing to the same small number.

Another aspect related to BCR processing that would be of interest to the present application is the computation of the intrinsic inverse C^{X} , of the covariance matrix C. In Project Memorandum 8512-03 it has been conjectured that if the inverse, C^{-1} , exists, then $C^{-1} = C^{X}$. This conjecture was tested in several practical examples and proved to hold true. Hence, the motivation exists to carry out a formal proof of a theorem stating the claim of Conjecture 2-2 in Project Memorandum 8512-03.

4.0 CONCULDING REMARKS

Modular library-based FORTRAN programs, SIGGEN, BCRS and BCRP have been developed for the purpose of conducting an adaptive nulling performance analysis of an adaptive array processing system using the BCR adaptive process. These Signal Generation, BCR Simulation and BCR Performance and Plotting programs have been described in great detail. A variety of specific examples have been worked out and presented demonstrating the usefulness of these programs. General performance results were also obtained with these programs and presented here.

The variety of different examples considered are characterized by distinct system and scenario descriptions. These include a choice of %RF bandwidth, single or multiple tap weighting, receiver mismatch, continuous, blinking or multipath incident noise sources, etc. As such, it was possible to examine nulling performance as a function of bandwidth, multiport or multitap weighting, receiver mismatch and choice of source type.

A general observation that could be made from the results obtained is that with increased RF bandwidth the number of adaptive weights needed for acceptable nulling performance will increase accordingly well beyond the number of incident sources. This behavior as demonstrated in both moderate and large-scale examples. This trend was even more pronounced in the case of multitap weighting.

Although many additional examples could have been run, the ones included here suffice to prove the usefulness of the modular programs developed. More importantly, using the input data file SIGGEN:D as the primary menu, the user has the capability of analyzing any number of examples that he might be interested in.

Furthermore, one may examine the performance of related adaptive systems by making appropriate modifications to existing library modules or creating new ones, as needed. The facility for doing this is the inherent advantage of the modular program structure that has been developed.

BCR ADAPTIVE PROCESSING

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BCR ADAPTIVE PROCESSING IMPLEMENTATION AND ITS PERFORMANCE EVALUATION VIA COMPUTER EMULATION

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1.0 INTRODUCTION

An effective digital implementation of the BCR process [1] should be characterized by an efficient architecture that guarantees reasonably high numerical precision. As an example, a floating-point implementation of BCR will provide the desired numerical accuracy, however, at the expense of a rather complex architecture. Consequently, a floating-point implementation of BCR is not effective. As another example, a fixed-point implementation of BCR may be architecturally efficient, however, it may not necessarily be numerically reliable. Hence, a standard fixed-point implementation may not be necessarily effective.

What constitutes an effective digital implementation of the BCR process is one employing fixed-point arithmetic equipped with a special form of adaptive scaling and overflow protection. Adaptive scaling enhances numerical resolution by inducing high-level bit-activity throughout the process while overflow protection insures against detrimental limit-cycle effects [2].

The present memorandum describes, in some detail, essential aspects of the adaptive fixed-point arithmetic underlying a particular digital implementation of a BCR processor.

A modular computer program, BCRM, is included which incorporates an exact model of the BCR processor. The benchtest example of Project Memorandum 8512-04 is used as a means of providing a detailed description of the program. The three examples included demonstrate the effective nulling performance of the BCR processor showing only a minor degradation with that of a floating-point simulation.

2.0 BCR PROCESSOR IMPLEMENTATION

As alreed escribed in Project Memorandum 8512-03, the BCR process applied to adaptive array processing consists of computing the covariance matrix C and a cross-correlation vector \underline{b} from a batch of auxiliary and main signal samples, solving the system $C\underline{w} + \underline{b} = 0$ for the weight vector \underline{w} via the CG algorithm and forming the minimum-interference combined signal, the weighted sum of the auxiliary signals combined with the main. Figure 2-1 shows these three stages of the BCR process.

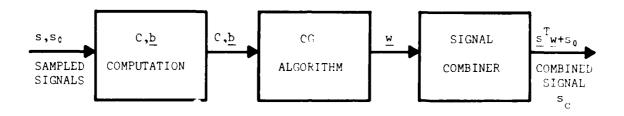


Figure 2-1. Three-Stage Representation of the BCR Adaptive Processor

The present section is primarily concerned with the description of the functional block diagram of the second stage of the BCR processor, since it is, by far, the most complex of the three. Included in the discussion is a qualitative explanation of the underlying adaptive fixed-point arithmetic employed. Pertinent discussion of the other two stages of computation are deferred to the next major section where the adaptive fixed-point arithmetic is formulated in great detail.

2.1 CG Algorithm

The particular form of the CG algorithm used \mathfrak{C} 0 solve Cw + b = 0 is the standard version already described in Project Memorandum $851\overline{2}$ -03. This specific version is included below for convenient reference.

(i) Let the initial estimate for the weight vector $\underline{\mathbf{w}}$ be $\underline{\mathbf{w}}^0 = \underline{\mathbf{0}}$ and define the initial residual and search vectors $\underline{\mathbf{r}}$ and $\underline{\mathbf{p}}$ by $\underline{\mathbf{p}}^0 = \underline{\mathbf{r}}^0 = \underline{\mathbf{b}}$.

At iteration k + 1,

(ii) Compute the relaxation coefficient

$$\alpha_{k} = \frac{\|\underline{r}^{k}\|^{2}}{(\underline{p}^{k}, \underline{c}\underline{p}^{k})}$$
 (2-1.1)

(iii) Update the weight vector by

$$\underline{\mathbf{w}}^{k+1} = \underline{\mathbf{w}}^k - \alpha_k \underline{\mathbf{p}}^k \tag{2-1.2}$$

(iv) Update the residual vector by

$$\underline{r}^{k+1} = \underline{r}^k - \alpha_k c\underline{p}^k \tag{2-1.3}$$

(v) Computer the Gram-Schmidt coefficient

$$\beta_{k} = \frac{\|\underline{r}^{k+1}\|^{2}}{\|\underline{r}^{k}\|^{2}}$$
 (2-1.4)

(vi) Update the relaxation vector by

$$\underline{p}^{k+1} = \underline{r}^{k+1} + \beta_k \underline{p}^k \tag{2-1.5}$$

(viii) If k + 1 = N or $||r^{k+1}||^2 < \varepsilon$, a preassigned small number, the process is stopped. Otherwise, replace k + 1 by k and return to (ii).

Other versions of this algorithm exist [3], [4], however, this particular form is especially convenient from the implementation and operational point of view.

2.2 Elements of Adaptive Arithmetic

In mechanizing the CG algorithm via fixed-point arithmetic, it is important to realize that a significant loss in numerical precision may occur

unless aptoministe adaptive scaling measures are incorporated into the process. The intent in employing adaptive scaling is to maintain maximum numerical resolution by forcing high-level bit activity before going into an arithmetic operation that is followed by truncation. Doing this insures minimum roundoff error. The cumulative history of bit shifts that takes place while exercising adaptive scaling must be accounted for throughout the process in order to properly interpret and use the numerical quantities generated. Finally, the risk of potential overflow must be averted at critical points in the process.

2.2.1 Local and Global Scaling

The specific form of adaptive fixed-point arithmetic, envisioned in implementing the BCR process, involves scaling by variable, whether it be vector or scalar, real or complex. In general, the left justification of a complex vector variable involves upshifting all words that comprise it by the number of bits that will left-justify the maximum-magnitude word. The single number that is associated with the left-justification of a given BCR variable is referred to as the local scale, because it occurs locally within the process and is not explicitly dependent on any other relationship.

Considering the iterative nature of the BCR process, local scaling will be exercised repeatedly on each and every variable involved. As such, in order to keep track of the absolute numerical value of each variable, it is imperative to have a cumulative history of the local bit-shifts as they occur. Furthermore, recognizing that a given variable is an interaction of several others, it must be identified with a cumulative global shift which is functionally related to the global shifts of the interacting variables, including any local shift or truncation that the given variable may have experienced. By associating a given BCR variable with its global scale, its absolute value is defined with respect to a convenient reference.

2.2.2 Overflow Protection

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In performing a summation function of two or more digital words having the same global scale, overflow protection is assured by providing all necessary bit-space for growth or by inducing single-bit downshifts at each stage of addition. The latter approach, although seemingly convenient, is numercially inferior in comparison to the former which is intended to minimize roundoff errors in the final truncated result.

When adding two left-justified digital words of varying global scales, scale equalization must be performed. Almost invariably, one of the words will have to be downshifted before the addition can take place. As such, if the downshift required is beyond the capability of the implementation, a system-interrupt command must intervene to stop the BCR process. Obviously, if the addition were allowed to occur without appropriate scale-equalization, the invalid result would most probably induce a limit-cycle into the BCR process in the form of uncontrolled overflows, rendering it inoperable. It should be pointed out that this special form of overflow

protection would be useless if it were not for the fact that the existing variable \underline{w} at the time of termination constitutes a valid estimate of the desired solution.

2.3 Functional Block Diagram

The mechanics of implementing adaptive fixed-point arithmetic in a hardware realization of the CG algorithm consists of judiciously locating special networks to perform necessary scaling functions at various stages of the CG process. Depending on their proculiar location, these scaling networks may be autonomous, externally-commanded or be capable of both options.

Figure 2-2 shows the functional block diagram corresponding to a 4-port 16-bit CG implementation. Major blocks in the diagram are clearly identified. Included are four distinct scaling networks, designed to implement the mechanics of adaptive arithmetic under the supervision of the "Global Scaling and Control" (GSC) block. The GSC block in combination with the block labeled "System Timing and Control" (STC) constitutes the Operating System of the BCR processor implementation.

2.3.1 Major Block Functions

In order to gain a clear understanding of the basic operation of the BCR process as implemented in the block diagram of Figure 2-2, it is important to define the operational characteristics of each of the major blocks that comprise it.

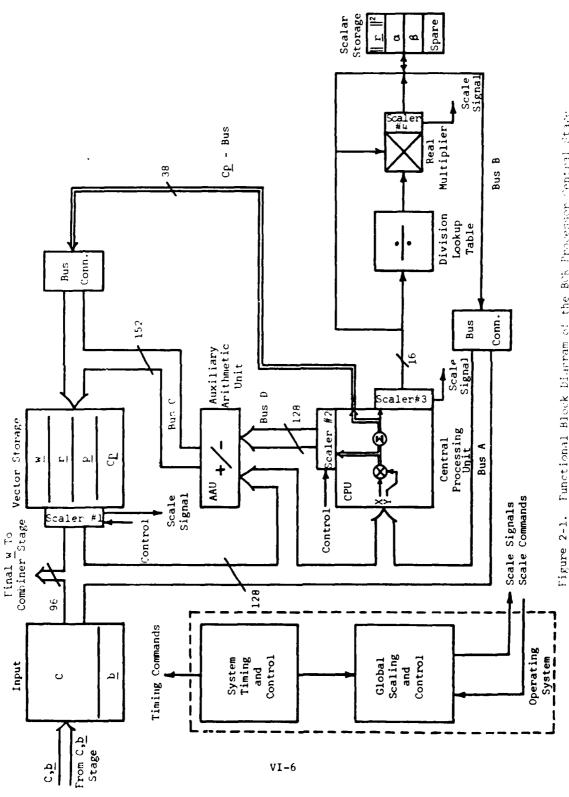
2.3.1.1 Input Block

In general, the input block consists of RAM for the purpose of accepting and storing the complex covariance matrix C and the complex forcing vector \underline{b} derived from the preceding C and \underline{b} stage of computation. More specifically, before entering the input block, C and \underline{b} are locally block-scaled independently and truncated to 16 bits. In a manner of speaking, these two variables have been AGC'd.

As shown in the block diagram, the C and \underline{b} data are made available to other blocks in the system via the 128-bit Bus \overline{A} . Accordingly, it is possible to access b in parallel and C serially, one row at a time.

2.3.1.2 Vector Storage

The Vector Storage block consists of sufficient RAM to store the BCR complex vectors $\underline{\mathbf{w}}$, $\underline{\mathbf{r}}$, $\underline{\mathbf{p}}$, and $\underline{\mathbf{Cp}}$ with a 19-bit representation as entered via the 152-bit Bus $\underline{\mathbf{C}}$. These vectors are accessible, one at a time, through Scaler #1, a scaling network which produces a 16-bit properly vector-scaled representation, compatible with the capacity of Bus A. In this way, these vectors are made available to other blocks of the system as needed.



e 2-1. Functional Block Diarram of the BCE Processor Central Stage Mechanized for Adaptive Fixod-Foint Arithmetic

2.3.1.3 Auxiliary Arithmetic Unit (AAU)

The AAU is designed to add or subtract two 16-bit 4-dimensional complex vectors. As such, the AAU is particularly useful in performing the \underline{w} , \underline{r} , and \underline{p} updates according to relations 2-1.2, 2-1.3, and 2-1.5 of the BCR algorithm. In addition, this block is instrumental in setting up the initial conditions of the BCR process, namely, $\underline{w}=0$ and $\underline{p}=\underline{r}=\underline{b}$. This is done by introducing the desired initial value in the Bus A input while setting the Bus D input to $\underline{0}$. The resulting output is routed through Bus C and loaded into the appropriate location in the Vector Storage RAM. Note that the + or the - option may be selected to perform the initial loading operation.

Since, in general, the 16-bit inputs to the AAU could give rise to a 17-bit left-justified output, Bus C must have a minimum capacity of 136 bits. The reason it is shown to have the larger capacity of 152 bits is that its Cp-branch requires it. This will be made clear later.

2.3.1.4 Central Processing Unit (CPU)

The CPU is designed to compute a dot product of two 4-dimensional 16-bit complex vectors. With variations of this basic operation, the CPU is capable of generating BCR quantitities $||\underline{r}||^2$, Cp, (p,Cp), αp , αCp and βp . Accordingly, the CPU is composed of four complex multipliers followed by an appropriate summation function.

Each complex multiplier is composed of a quad of 16-bit real multipliers operating with a selectable 16 or 15-bit truncation depending on the particular need for overflow protection. Note that when multiplying two maximum-magnitude negative 16-bit words, the positive result overflows into a 32nd bit, the overflow bit. To avoid this potential overflow, a 16-bit truncation is applied in general even though it is needed only in the instance indicated. As such, the resulting 16-bit output will generally have one sign-bit extension except in the case stated. However, the loss of this one bit of resolution need not be suffered when the multiplication is known to involve other than two negative numbers.

The summation function consists of three stages. The first stage is devoted to producing the four truncated complex componentwise products of the two input vectors. A given componentwise product results from the summation of appropriate pairs of 16-bit truncated real multiplier products which may be accommodated within 17 bits. The four complex componentwise products are subsequently summed pairwise over two more stages of addition to form a 19-bit complex scalar quantity that represents the dot product of the two 4-dimensional complex input vectors. It should be noted that rather than dropping a bit at each stage of summation and thus preserving a convenient 16-bit activity throughout, the preservation of the three bits over the three stages of summation limits the undesired propagation of roundoff error into subsequent operations.

Ar. important feature of the CPU is that it can perform a dot-product of two 4-dimensional complex vectors one of which may be used directly or in its conjugate form via a selectable variation in structure.

The specific computation of $\|\underline{r}\|^2$ involves the dot product of \underline{r} with \underline{r}^* . First, the \underline{r} vector is accessed from the Vector Storage Ram, left-justified by Scaler #1, truncated to 16 bits, placed on Bus A and latched into the X-port of the CPU. Repeating this process, \underline{r} is similarly latched into the Y-port. Selecting the conjugate option on Y, a dot product operation yields the desired 19-bit result, $\|\underline{r}\|^2$.

The Cp computation proceeds as follows. First, the p vector is accessed from the Vector Storage RAM, left-justified by Scaler #1, truncated to 16-bits, placed on Bus A and latched into the X-port of the CPU. Then, the first row of C is taken from the Input Block, placed on Bus A and latched into the Y-port. A normal dot product operation by the CPU yields a 19-bit complex scalar that constitutes the first component of the Cp vector. The 38-bit Cp-Bus takes this result and conveys it, via a Bus-Connect network, onto the appropriate partition of Bus C and loads it into the corresponding partition of the Cp RAM location. Repeating this process with all subsequent rows of C completes the componentwise generation of the Cp vector.

The computation of the theoretically positive real scalar quantity (\underline{r} ,C \underline{p}) is very similar to that of $\|\underline{r}\|^2$ already described. Note that, more explicitly, this inner product is equivalent to $\underline{p}^*TC\underline{p}$ or $\underline{p}^T(C\underline{p})^*$, since it is real. Consequently, the choice of conjugation is based on convenience of execution.

The remaining computation of αp , $\alpha C p$, and βp are all accomplished in a similar way. It suffices to discuss only the αp computation. Assume that p is already latched into the X-port of the CPU. The real number α is presented to a Bus Connect network and is fanned out into a uniform real-valued 4-dimensional vector, each component os which is equal to α + j0. Placed this way as Bus A, this uniform vector is subsequently latched into the Y-port. The desired vector dilation is available at or prior to the first stage of summation.

In carrying out the computations of $\|\underline{r}\|^2$, Cp and (p,Cp), the individual real multipliers comprising the CPU are overflow protected by means of one overflow-bit allowance. As mentioned before, this is necessary because of the possibility of multiplying two maximum-magnitude negative numbers which will yield a positive number with a single bit of overflow. The corresponding truncation at each multiplier output is noted to be 16 bits. In contrast, to the mentioned computations, quantities αp , αCp , and βp constitute products involving the known positive real parameters α and β . As such, the feared overflow condition cannot occur in any of these cases. For this reason, the overflow protection option is foregone here thus allowing an extra bit of resolution in each resulting quantities. The corresponding trunction at each multiplier output in the latter set of computations is 15 bits.

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2.3.1.5 Real Scalar Section

The section of the BCR block diagram that is devoted to computing and storing the positive real scalar parameters α and β is appropriately referred to as the Real Scalar Section. This major BCR block involves a Division Lookup Table, a real multiplier and RAM storage for the positive real scalars $\|\underline{r}\|^2$, α and β .

The Division Lookup Table is designed to accept a 16-bit fully-justified positive real input and produce a 16-bit fully-justified output that represents the reciprocal of the input. An implicit local scaling coefficient is taken into account.

Computations of α and β are similar, as indicated by relations 2-1.1 and 2-1.4 of the BCR algorithm. It suffices to discuss the process for computing α . The positive real 19-bit scalar quantity $(p,\,Cp)$ is first locally-scaled by Scaler #3 to full significance and then truncated to a 16-bit fully-justified form. Presented this way to the Division Lookup Table yields the fully-justified 16-bit version of its reciprocal 1/(p, Cp). Using a 16-bit real multiplier, this reciprocal is multiplied by the RAM-accessed $\|\underline{r}\|^2$ quantity, yielding α . Note that the multiplier does not require overflow protection since only positive inputs are involved. It should also be mentioned that Scaler #4 at the real-multiplier output locally-scales α or β to full-justification prior to storing or proceeding to further computation.

2.3.2 Essential Operational Aspects

The previous section discussed briefly the functions performed by some major blocks of the central BCR processor stage. In actual operation these individual blocks must be capable of interacting appropriately in order to maintain numerical integrity in the execution of the BCR process. To a large extent, the overall operation of the BCR process is essentially evident upon careful examination of the block diagram and the description of the major block functions already offered. Discussed below are two essential operational aspects of the BCR implementation which should serve to give a more complete understanding of the overall system operation.

2.3.2.1 Vector Updating

At each iteration of the BCR process the vector variables \underline{w} , \underline{r} , and \underline{p} are updated by means of incremental changes $\alpha \underline{p}$, $\alpha \underline{C} \underline{p}$, and $\beta \underline{p}$ according to relations 2-1.2, 2-1.3, and 2-1.5, respectively. The updating process itself is accomplished by means of the AAU and with appropriate use of Scalers #1 and #2.

Consider, for example, the updating of vector \underline{r} . The current vector \underline{r} resides in the Vector Storage RAM, the input to Scaler #1. The corresponding updating vector increment αCp is available at the input of



Scaler #2. Because αCp is essentially left-justified except for one sign-extended bit 75% of the time, Scaler #2 is provided only with the ability to downshift up to 15 bits, by external command. On the other hand, Scaler #1 is given the capability of autonomous or local shifting up to a limit of 8 bits. At the same time, it also has the capability of shifting down by as much as 7 bits via external command. With the combined capabilities of these two scaling networks, it is possible to combine the current \underline{r} with its increment αCp thus accommodating a sufficiently large dynamic range of numbers.

The actual updating process for \underline{r} proceeds as follows. First, Scaler #1 senses the number of upshifts necessary to left-justify \underline{r} without actually executing the local scaling. This number, which is limited to 8, is then incorporated into the global scale coefficient identified with \underline{r} . Comparing this global scale or \underline{r} with that of α Cp determines which one of the two quantities must be shifted down from its fully-upshifted position before combining. Note that although the maximum downshift on Cp is a constant 15 bits, that of \underline{r} is a variable 7 bits plus the sensed upshift. In fact, if the sensed local upshift for \underline{r} is $k_{\underline{r}}$, a maximum downshift of 7 + $k_{\underline{r}}$ may be obtained by accessing \underline{r} from RAM with an external shift-command corresponding to 7 downshifts. The downshift necessary is that which will allow the global scales of the two quantities to be equal before properly combining. This is global scale equalization, as mentioned previously.

2.3.2.2 Terminal Conditions and Stopping Criteria

When global scale equalization cannot be achieved within the implemented limits, the BCR process must be commanded to stop. The current value of \underline{w} at the point of termination constitutes the best estimate of the solution within the numerical capability of the machine. It should be noted that the shifting range available appears to be sufficient to support a solution to an 8-bit accuracy. This has been substantiated in a number of cases investigated by means of computer emulation.

Besides the above, there is another natural terminal condition. This occurs in the Real Scalar Section at the input to the Division Lookup Table. If a 01 bit-activity is not detected there, the Division Table no longer applies and a termination condition occurs.

While the above termination conditions serve as unavoidable stopping criteria, there does exist at least one natural way to call for system-interrupt. In particular, when $\|\underline{r}\|^2/\|\underline{b}\|^2 < 2^{-15}$, BCR convergence has been achieved. Of course the default stopping option is the iteration count of four, the dimensionality of the system under consideration.

It should be pointed out that, with the termination conditions and stopping criteria available, the BCR implementation is completely overflow-protected under any circumstances.

3.0 BCR OPERATING SYSTEM

It has been mentioned previously that, strictly speaking, the Operating System for the BCR process consists of the composite of System Timing and Global Scaling and Control functions. Since a detailed definition of the BCR System Timing will be given in a future project memorandum, the emphasis in this section will be placed on developing the specifics of the Global Scaling and Control function, the very precise rules that govern the adaptive fixed-point arithmetic of the BCR implementation.

3.1 Prescaling and Postscaling

Given sequences $\{s_0(m)\}_{m=1}^M$ and $\{\underline{s}(m)\}_{m=1}^M$ representing main scalar and auxiliary vector M-sample complex baseband signal batches, it can be shown [1] that the covariance matrix is given by

$$C = (\underline{s}, \underline{s}^{T})$$

$$= \sum_{m=1}^{M} \underline{s}^{*}(m)\underline{s}^{T}(m) \qquad (3-1)$$

and the cross-correlation vector by

$$\underline{b} = (\underline{s}, s_0)$$

$$= \sum_{m=1}^{M} \underline{s}^{*}(m)\underline{s}_{0}(m) \qquad (3-2)$$

Computed in this manner by means dedicated circuitry, C and b are subsequently locally scaled independently and truncated to 16 bits. More specifically, b is vector-scaled locally by upshifting all real and imaginary words involved in unison so that the maximum-magnitude word is left-justified. Subsequently, all words comprising b are truncated to 16 bits. Matrix C is locally scaled in a similar way. Note that the amount of upshift in this case is determined by examining the purely real diagonal elements, one of which happens to be the largest-magnitude word of all that comprise C.

Let us define the respective local scales on C and \underline{b} by symbols KC and KB, the number of upward bit-shifts required for full justification.

Also, assume KT to be the common number of truncation bits required to limit C and \underline{b} to 16 bits. Then, in terms of original C and \underline{b} quantities, the equation to be solved is

$$2^{\text{KC}}C\underline{w} + 2^{\text{KB}}\underline{b} = \underline{0} \tag{3-3}$$

whence, symbolically,

$$\underline{\mathbf{w}} = -2^{\mathrm{KWF}}\underline{\mathbf{w}}^{\mathrm{O}} \tag{3-4}$$

with RW! = KP - KC, the effective local shift on the final solution, w', with respect to the actual, $\underline{w}^0 = C^{-1}\underline{b}$. In other words, whatever the correct solution of \underline{w} is, the solution obtained via BCR with locally prescaled C and \underline{b} quantities is in fact 2KWF larger. This discrepancy must be taken into account with appropriate postscaling at the combiner stage, the last stage of the BCR processor.

3.2 Global Scaling Equations and Control

The adaptive fixed-point arithmetic underlying the BCR implementation is mechanized with the aid of a special set of equations that accounts for the bit-shift history of all the variables involved. Specifically, each variable is associated with a global bit-shift number that relates it to some convenient reference. This global bit-shift reflects the local-shift experienced by the associated variable, global shifts from interacting variables and any truncation that might be exercised.

What follows constitutes a detailed development of the global scaling equations associated with the BCR variables and accompanying commands that provide appropriate control of the process via the special scaling networks involved.

3.2.1 Initial Conditions

Referring to the functional block diagram of the BCR process given in Figure 2-1, assume that the prescaled C and b quantities are available in PROM or RAM at the Input block. In accordance to the algorithm, the BCR process is initialized by setting $\underline{w} = \underline{0}$ and $\underline{p} = \underline{r} = \underline{b}$. Specifically, this involves loading the zero vector, $\underline{0}$, into the \underline{w} -vector location of the Vector Storage RAM. Similarly, \underline{b} is loaded into the \underline{r} and \underline{p} locations. As already mentioned, this initial loading process is accomplished through the use of the AAU.

Irrespective of the value of the prescaling differential shift for \underline{w} , namely, KWF, we may arbitrarily define the global bit-shift coefficients for \underline{w} , \underline{r} , and \underline{p} to be zero. That is, we let

$$LW = LR = LP = 0 \tag{3-5}$$

Recall that in loading the Vector Storage Ram with the initial values of \underline{w} , \underline{r} and \underline{p} through the AAU, the Bus D input is set to $\underline{0}$ while the desired loading value is placed at the Bus A input. Choosing, arbitrarily, the \underline{t} option, the initial loading value appears at the Bus C output of the AAU from where it is conveyed to its proper storage location. To prevent potential overflow during general operation, one overflow bit must be allocated to each and every word at the AAU output. For this reason Bus C must be at least 136 bits wide. As a consequence, the proper access of the initally loaded values of \underline{r} and \underline{p} from storage onto the 128-bit Bus A will require a 1-bit upshift, followed by a 1-bit truncation. Provisions for accomplishing this are available at scaling network #1.

In the process of initially loading \underline{b} into the \underline{r} -location of the Vector Storage RAM, \underline{b} may also be latched into the X-port of the CPU. While subsequently loading \underline{b} into the \underline{p} location of the RAM, \underline{b} may simultaneously be latched into the Y-port of the CPU. Employing the conjugate-option on the Y-port and the 16-bit truncation-option on the individual real multipliers of the CPU, the real scalar quantity $\|\underline{r}\|^2$ is computed in three subsequent stages of addition, yielding a 19-bit real word. Specifically,

$$\|\underline{r}\|^2 = Re \sum_{i=1}^4 r_i r_i^*$$
 (3-6)

Note that the first stage of summation is understood to be associated with the individual complex products $r_1r_1^*$. As such, the individual complex products are accommodated in dual 17-bit words. The sum of the four products indicated in (3-6) accounts for the additional 2-bit growth.

The 19-bit real scalar quantity $\|\underline{r}\|^2$ is then presented to scaling network #3 which senses and executes the needed local shift for left-justification. Limited to 15 bits of upward shift capability, this scaling network subsequently truncates the bottom three bits and transmits a fully-justified 16-bit version of $\|\underline{r}\|^2$ to the Scalar Storage RAM via Bus B. Letting

KRRH = the hardware local shift on $\|\underline{r}\|^2$ provided by scaling network #3, limited to 15 bits of upshift

KRRO = the effective 3-bit truncation of $\|\underline{r}\|^2$ from 19 bits to 16 bits, after scaling

KRR = KRRH - KRRO

= the effective local shift of $\|\underline{r}\|^2$ referred to 16-bit arithmetic

then, the global scale of the 16-bit representation of $\|\underline{r}\|^2$ as stored in RAM is given by

$$LRR = LR + LR + KRR - KM$$
 (3-7)

where

LR = the global scale of the 16-bit version of the initial value of \underline{r} as is available at Bus A or at the X and Y ports of the CPU

KM = the 16-bit truncation at each individual real multiplier of the CPU

Clearly, LR is involved twice in (3-7) since \underline{r} is essentially multiplied by itself.

The time devoted to computing the intial value of $\|\underline{r}\|^2$ is referred to as the initialization period and must be distinguished from the rest of a given iteration. Accordingly, upon completion of an iteration, the process returns to a computing cycle immediately following the initialization period. Note that the computation of $\|\underline{r}\|^2$ within the initialization period is dictated naturally by the fact that subsequent $\|\underline{r}\|^2$ values are already being computed for the sake of evaluating β .

3.2.2 Complete BCR Iteration

The repeating portion of the BCR iteration may logically start with the computation of Cp. First, p is accessed from Ram with maximum upshift and truncated to 16 bits with the aid of Scaler #1, placed on Bus A and latched into the X-port of the CPU. Considering that Scaler #1 has a limited upshift capability of 8 bits, p might not be completely left-justified at the X-port. In any case, letting

KPH = the hardware local scale on p provided by Scaler #1, limited to 8 bits of upshift.

KPO = the effective 1-bit truncation of \underline{p} from 17 to 16 bits, after scaling

KP = KPH - KPO

= the effective local scale of \underline{p} referred to 16-bit arithmetic

then, given that the global scale of \underline{p} in RAM is LP', its global scale at the X-port of the CPU becomes

$$LP = LP' + KP (3-8)$$

The CP-computation is then executed as follows. Successive rows of C are accessed from the Input Block and latched into the Y-port of the CPU. Performing normal dot products yields $C\underline{p}$, one component at a time, according to

$$(c_{\underline{p}})_{i} = \sum_{j=1}^{4} c_{ij}P_{j}$$
 (3-9)

with i = 1, 2, 3, 4. As in the case of $\|\underline{r}\|^2$, the sequentially generated complex components of Cp are represented by dual 19-bit words. Accordingly, a 38-bit Cp-Bus is used to convey each component onto the 156-bit Bus C via a specially-designed Bus-Connect network and storing it appropriately within the Cp-location of the Vector Storage RAM. Keeping in mind the multiplier truncation within the CPU, the global scale of the Cp vector in RAM happens to be

$$LCP' = LP - KM (3-10)$$

where.

LP = the global scale of vector \mathbf{p} at the X-port of the CPU

KM = the 16-bit truncation of the individual real multipliers of the CPU

With Cp in RAM, the computation of the real scalar quantity (p,Cp) follows. Specifically, this quantity is given by

$$(\underline{p},\underline{c}\underline{p}) = Re \sum_{i=1}^{4} p_{i}^{*}(\underline{c}\underline{p})_{i}$$

$$= Re \sum_{i=1}^{4} p_{i}(c_{\underline{p}})_{i}^{*}$$
 (3-11)

Since \underline{p} is already available at the X-port of the CPU, \underline{Cp} is accessed from RAM with maximum upshift and truncated to 16 bits with the aid of Scaler #1, placed on Bus A and latched into the Y-port. Accordingly, letting

KCPH = the hardware local shift on Cp provided by Scaler #1, limited to 8 bits of upshift

KCP = KCPH - KCPO

= the effective local scale of Cp referred to 16-bit arithmetic

then, the global scale of Cp at the Y-port of the CPU is given by

$$LCP = LCP' + KCP$$
 (3-12)

Employing the conjugate-option on the Y-port and the 16-bit truncation option on the individual real multipliers of the CPU, the desired real scalar quantity $(\underline{p},C\underline{p})$ is computed in the very similar way as $\|\underline{r}\|^2$. Letting

KPCPO = the effective 3-bit truncation of $(\underline{p},C\underline{p})$ from 19 bits to 16 bits, after scaling

KPCP = KPCPH - KPCPO

= the effective local scale of (p,Cp) referred to 16-bit arithmetic

KM = the 16-bit truncation of the real multipliers of the CPU

then, the global scale of the 16-bit left-justified version of $(\underline{p},C\underline{p})$ as presented into the input of the Division Lookup Table is given by

$$LPCP = LP + LCP + KPCP - KM$$
 (3-13)

The Division Lookup Table is designed to accept a positive real left-justified 16-bit word and yield a 16-bit left justified version of its reciprocal. Consequently, the output is understood to have an implicit 29-bit local shift. Letting

KD = the 20-bit implicit local shift in the Division Lookup Table

then, the global shift of the reciprocal $1/(\underline{p},C\underline{p})$ at the input to the real multiplier is simply

$$LPCPI = KD - LPCP$$
 (3-14)

The computation of α follows immediately. Accessing $\|\mathbf{r}\|^2$ directly from RAM, it is presented to the other input of the real multiplier. The product of $\|\mathbf{r}\|^2$ and 1/(p,Cp) yields α . Since both of these quantities are positive, the 15-bit truncation-option is used to obtain a 16-bit output which is subsequently left-justified. Letting

KAL = the hardware or effective local scale on α , limited to 2 bits

KMO = the 15-bit truncation at the real multiplier

then, the global scale for α is given by

$$LAL = LRR + LPCPI + KAL - KMO$$
 (3-15)

At the same time α is being stored in RAM, it is also routed via Bus B, fanned out uniformly on Bus A via the special Bus-Connect network at the juncture and latched into the Y-port of the CPU. With p already available at the X-port, the real dilation αp is obtained by employing the partial dot-product option in the CPU. Then, at the input of Scaler #2, the global scale of p is given by

$$LAP = LAL + LP - KMO (3-16)$$

Note here that the truncation at each real multiplier is 15 bits since α is a positive real scalar. Also, since \underline{p} and α are left-justified going into the CPU, $\alpha\underline{p}$ is left-justified with a probability of 0.25 and is at most one bit away from full justification. Accordingly, for purposes of general simplification, Scaler #2 is not given the capability of upshifting. In fact, Scaler #2 is designed to downshift only up to a limit of 15 bits.

With αp available at the input to Scaler #2 and the current w in the Vector Storage RAM proceeding Scaler #1, the updated 17-bit version of w, w - αp , may now be obtained via the AAU following scale equalization. Specifically, the global scales of w and αp must be adjusted to a common level such that one of the two quantities is placed at the highest possible significance. Note that if w were to be viewed at maximum upshift and considering that ap is already at maximum possible significance, scale equalization will be achieved by shifting one of the two quantities downward by a number of bits within an associated limit. Of course, w must not be explicitly upshifted by Scaler #1 because there is no provision for subsequently downshifting, if it is deemed necessary. Rather, we may sense the maximum hardware shift that may be provided by Scaler #1 without actually applying it. As such, the global scale of w incorporating the maximum upshift would correspond to a virtual maximum upshifted version of w. A downshift from this virtual state of w is possible with an appropriate external command to Scaler #1. This argument may be made more precise in quantitative terms. Let

KWH = the hardware local scale on \underline{w} as sensed by Scaler #1, limited to 8 bits of upshift

KW0 = the effective 1-bit truncation of w from 17 to 16 bits, after scaling

KW = the effective local scale of w, KWH - KWO,
 referred to 16-bit arithmetic

Then, the global scale of a maximally-upshifted virtual w is given by

$$LW = LW^{2} + KW \qquad (3-17)$$

where LW is the global scale of w in RAM.

Suppose that, upon comparing (3-16) with (3-17), we have that LAP = LW. Then, the desired w-update involves accessing w from RAM at the maximum-upshift provided by Scaler #1, passing op through Scaler #2 at zero-downshift and subsequently performing the appropriate subtraction at the AAU. In this special case, the global scale of the updated 17-bit w is given by

$$LW' = LW \tag{3-18}$$

In the case when LAP > LW, αp must be downshifted by a number of bits equal to the differential shift LAP - LW, while w is upshifted fully at Scaler #1. Note that this includes the previous special case and that the global scale of the updated w is as given in (3-18). Also, it should be mentioned that the maximum positive differential shift that may be accommodated is 15 bits.

When LAP < LW, the scale equalization procedure is a little more involved. Keeping in mind that \underline{w} may be downshifted by as much as 7 bits, the maximum negative differential shift LAP - LW that could be tolerated is -(KWH + 7). In the specific case where KWH = 0, a maximum downshift of 7 bits can be provided by Scaler #1 with up remaining as is, \underline{w} is accessed through Scaler #1 and downshifted by LW - LAP from its fully upshifted position. † This is done by an appropriate command, namely a shift of KWH + LAP - LW. The global scale of the update 17-bit \underline{w} in this case is

$$LW' = LAP (3-19)$$

As an example, let KWH = 5 and LAP - LW = -3. Then, the command to Scaler #1 in accessing \underline{w} from RAM is such that it effects an upshift of KWH + LAP - LW = 2.

It should be mentioned here that, since the initial value of \underline{w} has been chosen to be $\underline{0}$, the updated \underline{w} at the first iteration is simply - αp . The scale equalization logic described above for properly performing the \underline{w} -update may thus be circumvented at the first iteration. As far as the global scale of the updated \underline{w} is concerned, it is given by (3-19).

The computation of αCp may be started even before the <u>w</u>-update is over. Since α is already available as a uniform vector at the Y-port of the CPU, the Cp-vector may be accessed from RAM with maximum upshift through Scaler #1, placed on Bus A and latched into the X-port of the CPU. A partial dot-product operation leads to the dilation αCp at the input to Scaler #2. Letting

KCPH = the hardware local scale on \underline{w} as provided by Scaler #1, limited to 8 bits of upshift

KCP0 = the effective 3-bit truncation of Cp from 19 to 16
 bits after scaling

KCP = the effective local scale of Cp, KCPH - KCPO, referred
to 16-bit arithmetic

Then, the global scale of the maximally upshifted 16-bit version of $C\underline{p}$, as presented to the X-port of the CPU, happens to be

$$LCP = LCP' + KCP (3-20)$$

where LCP' is the global scale of Cp in RAM. The global scale of α Cp at the input to Scaler #2 is given by

$$LACP = LAL + LCP - KMO (3-21)$$

where, of course, KMO is the optimal 15-bit truncation applied at each of the individual multipliers in the CPU.

The updating process of \underline{r} may now take place in a manner similar to that of updating $\underline{w}.$ Letting

KRH = the hardware local scale on <u>r</u> as sensed by {caler #1, limited to 8 bits KR0 = the effective 1-bit truncation of \underline{r} from 17 to 16 bits, after scaling

KR ≈ KRH - KRO

= the effective local scale of \underline{r} referred to 16-bit arithmetic

then, the global scale of a maximally upshifted virtual r is given by

$$LR = LR' + KR (3-22)$$

where LR´ is the global scale of \underline{r} in RAM.

Consider the case where LACP - LR < 0. Then, \underline{r} is accessed on Bus A at maximum upshift through Scaler #1 and α Cp is downshifted by a number of bits equal to the differential shift, LACP - LR, but not exceeding the full 15-bit downshift capability of Scaler #2. Upon thus achieving scale equalization, the updated \underline{r} -vector is obtained by forming the difference \underline{r} - C \underline{r} via the AAU. The global scale of the 17-bit updated \underline{r} -vector is then given by

$$LR' = LR \tag{3-23}$$

When, on the other hand, LACP - LR < 0, then α Cp is left alone while the r-vector is downshifted from its virtual fully upshifted state within the capability of Scaler #1. The command to Scaler #1 is, in fact, one corresponding to an absolute shift of KRH + LACP - LR. Of course, as mentioned before, the maximum negative differential shift that can be accommodated is -(KRH - 7) = -(KR + 8), since KRO = 1. In this case, the global scale of the updated 17-bit r-vector is simply

$$LR^{\prime} = LACP \qquad (3-24)$$

The updated r in RAM may now be accessed at maximum upshift through Scaler #1, placed on \overline{B} us A and latched into the X-port of the CPU. Accessed again, it is latched into the Y-port. Letting

KRH = the hardware local scale on r as provided by Scaler #1, limited to 8 bits of upshift

KRO = the effective 1-bit truncation of \underline{r} from 17 to 16 bits, after scaling

KR = KRH - KRO

= the effective local scale of \underline{r} referred to 16-bit arithmetic

Then, the global scale of the maximally upshifted 15-bit \underline{r} vector at the X and Y ports of the CPU happens to be

$$LR = LR + KR (3-25)$$

Employing the conjugate-option on the Y-port, the CPU yields the 19-bit real scalar $\|\underline{r}\|^2$ at the input to Scaler #3. Locally scaling to full significance and truncating by 3 bits yields the left-justified 16-bit version of $\|\underline{r}\|^2$ whose global scale is given by

$$LRR = LR + LR + KRR - KM \qquad (3-26)$$

the identical expression used in the initialization period involving the first $\|\underline{r}\|^2$ computation.

Frior to storing the newest $\|\underline{r}\|^2$ into the Scalar Storage RAM, the previous $\|\underline{r}\|^2$ value is accessed, presented to the Division Lookup Table and its 16-bit left-justified reciprocal made available at one input of the real multiplier. During this exact time, the newest $\|\underline{r}\|^2$ on its way to RAM is also presented to the other input to the multiplier. The locally scaled 16-bit product represents β which is sent simultaneously to RAM and around Bus B for further processing. Letting

LRR' = the global scale of the previous $||r||^2$

KD = the 29-bit implied upshift at the Division Lookup
Table

then, the global scale of the reciprocal of the previous $\|\underline{r}\|^2$ is given by

$$LRRI = KD - LRR^{\prime}$$
 (3-27)

whence, in view of (3-25), the global scale of β becomes

LBET = LRR + LRRI + KBET - KMO

where KBET is the local scale at the real-multiplier output and KMO is the optional 15-bit truncation prior to scaling.

With β at hand, the computation of $\beta \underline{p}$ follows easily. Prior to completing the computation of β , \underline{p} is accessed from RAM with maximum upshift as provided by Scaler #1, placed on Bus A and latched into the X-port of the CFU. Letting

MC = the effective 1-bit truncation of <u>r</u> from 17 to 16 bits, after scaling

KF = KPH - KPO

= the effective local scale of \underline{p} referred to 16-bit arithmetic

then, the global scale of the maximally upshifted 16-bit p-vector at the X-port of the CPU is given by

$$LP = LP^{\prime} + KP \qquad (3-28)$$

where LP' is its global scale of p in RAM.

As soon as β becomes available at the Scaler #4 output, it is conveyed along Bus B, fanned out into a uniform real vector via the available Bus-Connect network, placed on Bus A and latched into the Y-port of the CPU. A partial dot product subsequently yields βp which is presented to the input of Scaler #2 with a global scale that is given by

$$LBP = LBET + LP - KMO (3-29)$$

where KM0 is the optional 15-bit truncation at the individual real multipliers of the CFU.

The final step in the repeating portion of the BCR iteration involves the updating of p. Keeping in mind that the updated p is given by $\underline{r} + \beta \underline{p}$, scale-equalization of \underline{r} and \underline{p} must first be attained before performing the required summation via the AAU. Letting

KRH = the hardware local scale on <u>r</u> as sensed by Scaler #1, limited to 8 bits

KR0 = the effective 1-bit truncation of \underline{r} from 17 to 16 bits, after scaling

KR = KRH - KRO

= the effective local scale of \underline{r} referred to 16-bit arithmetic

then, the global scale of a maximally upshifted virtual r is given by

$$LR = LR^{2} + KR \qquad (3-30)$$

where Lk' is the global scale of r in RAM.

When LBP - LR \geq 0, r is accessed on Bus A at maximum upshift via Scaler #1 and βp is downshifted by LBP - LR bits prior to entering the AAU. The updated 17-bit p-vector which is subsequently entered into RAM has a global scale given by

$$LP' = LR \tag{3-31}$$

When LBP - LR < 0, βp is left alone. In contrast, \underline{r} is accessed from RAM through Scaler #1 with a shift of KRH + LBP - LR, provided it is within the variab's lower bound of -(KRH + 7). In this case, the global scale of the updated 17-bit p-vector sent to RAM is obviously

$$LP' = LBP (3-32)$$

3.2.3 Stopping Criteria

According to the CG algorithm as given in Section 2.1, the process may be terminated either when the iteration number is equal to the dimensionality of the system $C_{\underline{w}} + \underline{b} = \underline{0}$, or when $||\underline{r}||^2$ has become smaller than a preassigned small positive real number ε .

Since $\underline{r}^0 = \underline{b}$, a logical choice for ε is $2^{-15} ||\underline{b}||^2$. More specifically, the BCR process can be terminated prior to or during its last iteration if

$$\|\underline{\mathbf{r}}\| < 2^{-15} \|\underline{\mathbf{b}}\|^2$$
 (3-33)

which is consistent with the fact that the 16-bit arithmetic employed cannot possibly provide a resolution more reliable than one part in 2^{15} . For the sake of simplicity, the practical mechanization of (3-33) need not involve the actual numerical quantities $\|\underline{r}\|^2$ and $\|\underline{b}\|^2$ but, rather, an essentially equivalent statement in terms of their respective global scales. Letting LRRO represent the global scale of $\|\underline{b}\|^2$, or $\|r^0\|^2$, then, an easily implementable version of stopping condition (3-33) is

$$LRR - LRRO > 15$$
 (3-34)

Of course, this would require that LRRO, the initially computed global scale of $\|\underline{r}\|^2$, be stored and made available for comparison with subsequent global scales of $\|\underline{r}\|^2$ in accordance to (3-34).

Although the above two mentioned stopping conditions are necessary and sufficient in theory, in the context of a finite-bit machine they do not suffice. As an example, consider the operation of the Division Lookup Table. If Scaler #3 cannot left-justify (p,Cp) or $\|r\|^2$ prior to addressing the table, a system-interrupt must be induced, terminating the BCR process. Assuming that there exist no system malfunctions, this situation is indicative of the fact that Scaler #3 has exhausted all 15 upshifts without succeeding to left-justify the quantity in question. This, in turn, implies that the quantity involved is sufficiently small, indicating BCR convergence. The weighting vector $\underline{\mathbf{w}}$ in RAM may then be taken as the best estimate of the desired solution, within the numerical capability of the machine. It should be mentioned that when $\|\underline{r}\|^2$ is so small that it cannot be left-justified by Scaler #3, then the system $C\underline{\mathbf{w}} + \underline{\mathbf{b}} = \underline{\mathbf{0}}$ is satisfied within the accuracy of the 16-bit arithmetic employed. Noting that (p,Cp) is essentially an eigenvalue of C, when (p,Cp) cannot itself be left-justified by Scaler #3, then we have clearly exhausted the rank of C and the process must stop.

Another pertinent stopping condition is related to the nature of the updating process. Recall that, in connection with updating \underline{w} , \underline{r} , \underline{p} ,

Scaler #1 is limited to 8 bits of downshift. As such, if the incremental change on any one of these quantities is greater than 28 of that in RAM, then, scale-equalization cannot be effected and updating cannot take place any more accurately than 1 part in 28.

This scaling limitation may or may not prove to be detrimental to the operation of the BCR process. It might be argued that an error of 1 part in 28 may be tolerated considering the the signal samples that were used to form the 16-bit covariance matrix were themselves 8-bit samples. On the other hand, subsequent iterations may, in fact, magnify this error so much so as to give rise to numerical instability manifested, possibly, in the form of a limit-cycle. However, for theoretical reasons, it is desirable to terminate the process when scale equalization may not be accommodated. Very briefly, the phenomenon described above is indicative of the fact that the rank of the matrix has been exhausted at the iteration where it occurred and convergence has consequently been achieved. Of course, the first update of w from its initial value of 0 is excepted from this argument.

With the last two stopping conditions mechanized in the BCR implementation, the system is essentially overflow-protected. The set of four stopping conditions discussed constitute the stopping criteria that render the system numerically fail-safe.

3.2.4 Construction of the Combined Signal

At the termination of execution in the CG algorithm stage of the BCR process, the weight vector $\underline{\mathbf{w}}$ is accessible locally-scaled by Scaler #1 at a 16-bit or some lower desired resolution, say NBW. In Figure 2-2, the indicated weight vector resolution to the signal combiner is 12 bits. Keeping in mind the implied scale discrepancy on $\underline{\mathbf{w}}$ of KWF at the (C,b)-stage of the BCR process, its global scale at the combiner is given by

LW = LW + KWF + NBW - NBP

where,

LW = the global scale of \underline{w} at the termination of the CG algorithm

KWF = the prescale discrepancy in the value of \underline{w}

Note that 7 bits of downshift are available through hardware; an additional 1 bit is due to bit-alignment in the case of r, p and w.

NBW = the desired bit-resolution of \underline{w} at the signal combiner. In the present case this value is 12.

NBP = the processor word length, which is 16 in the present case

As a consequence, the combined signal becomes

$$s_{c} = 2^{-LW} \underbrace{s}_{T} \underbrace{w}_{H} + s_{0}$$

which involves post-scaling the weighted sum of auxiliary signals, $\underline{s}^{T}\underline{w}$, by mechanizing a downshift of LW bits.

3.2.5 Summary Table

Global Scaling and associated control have been discussed to some detail in this section. For clarity and convenience, the entire set of global scaling equations including initial and terminal conditions have been summarized in the form of Table 3-1. Shown there is a set of numerical specifications indicating auxiliary and main signal word lengths, a 16-bit processor word length, 16 x 16-bit multiplications with optional 16 and 15-bit truncation, implicit local scaling of the 16-bit Division Lookup Table and effective truncations due to bit-alignments in bussing junctures.

The table i. subdivided into three columns, entitled "Operation", "Global or Local Scale Values and Equations" and "Remarks". Included are pertinent descriptions of the three BCR processor stages. Following the brief description of the C, b stage is the CG-stage. This second BCR stage is subdivided into two major portions, the "Initialization" followed by the "Iterative" portion. Included under "Operation", are initial conditions, equations, quantities to be computed and scaled. Listed under "Global or Local Scale Values and Equations" are local and global scale value or equations corresponding to quantities in the first column. Finally, under "Remarks" are found brief explanations regarding the origin of the scale information, indications of possible external commands and potential stopping conditions imposed numerically or by the particular implementation. The final BCR processor stage deals with related information about the actual signal combining, the stage where the combined signal is produced.

1

Numerical Specifications	Main Port Signal Word Length Auxiliary Port Signal Word Length Processor Word Length (including C,b) 16 x 16-bit Multiplier Truncation #1 16 x 16-bit Multiplier Truncation #2 Implicit Local S-ale by 16-bit Division Lookup Table Effective Truncation at Scaler #1 KRO, KPO, KWO Effective Truncation at Scaler #1 and #3 KCPO, KRRO, KPCPO: KT3 = 3 Desired Word Length to Combiner 10 NBW = 12	Global or Local Scale Values and Equations C.b Stage Prescaling	Computation KC Local scale for C. KB Local scale for $\overline{\bf b}$.
		Operation	C, E computation

Prescale discrepancy on final w. This quantity indicates the number of additional bits of upshift included in the value of w produced in the CG-stage that follows.	CG-Algorithm Stage Initialization	The initial indeterminate scale for $\underline{w} = \underline{0}$.	The global scale of $ \underline{r} ^2$ at the out of Scaler #3. Here, the effective local scale is KRR = KRRH - KRRO, where KRRH is the hardware scale limited to 15 bits of upshift and KRRO = KR3 is the effective truncation from 19 to 16 bits. No external command required.	Repeating Portion of Iteration	The global scale of p after it is accessed from RAM through Scaler #1. Here, LP is the global scale of p as stored in RAM and KP = KPH - KPO is the effective local scale, where KPH is the hardware scale limited to 8 bits of upshift and KPO = KTl is the effective truncation from 17 to 16 bits. No external command required.
KWF = KB - KC	1T	M.1 = 4.1	LR 4	Repeating	LP = LP + KP
		0 11 11 14 3 14			വ .

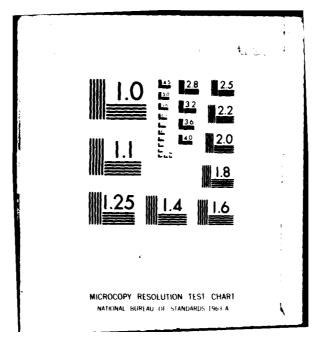
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	2 as sto	D as acc effecti ere KCPH upshift from 19	o,Cp) at is KFCP shift 1 effect command	he 16-bi ision Lo ide left on Looku	of α at the output of Scaler #4 al scale KAL is, in fact, equal fote that the multiplier trunca No external command required.	at the is required is used s
	ale of G	ale of Clere, the CPO, who sits of control of cation red.	al scale of (grandware f3 is the	scale of the 16-bit reciprocal of (P,CP) at of the Division Loopup Table. Note that if cannot provide left-justification of (P,CP) the Division Lookup Table, the process is	ale of α local so . Note l5. No	lle of αg scaling sft-just = 15 is
	The global scale of Cp as stored in RAM with 19-bit	The global scale of Cp as accessed from RAM through Scaler #1. Here, the effective local scale is KCP = KCPH - ECPO, where ECPH is the hardware scale limited to 8 bits of upshift and ECPO = ET3 is the effective truncation from 19 to 16 bits. No external command required.	The global scale of (p,Cp) at the output of Scaler #3. Here, the local scale is KFCP = KPCPH - KPCPO, where KPCFH is the hardware shift limited to 8 bits of upshift and KPCPO = KT3 is the effective truncation from 19 to 16 bits. No external command required.	The global scale of the 16-bit reciprocal of (p,Cp) are the output of the Division Loopup Table. Note that is scaler #3 cannot provide left-justification of (p,Cp) going into the Division Lookup Table, the process is terminated.	The global scale of α at the output of Scaler #4. Here the effective local scale KAL is, in fact, equal to the hardware scale. Note that the multiplier truncation used is KMO = 15. No external command required.	The global scale of αp at the input to Scaler #2. that no local scaling is required here since α an are already left-justified. Also, the multiplier truncation KMO = 15 is used since α is a positive scalar.
	The global resolution.	The RJ Scaler KCP = limite effect	The gl Here, KPCPH and KF	The global the output Scaler #3 c going into terminated.	The gl the ef hardwe	The glo that no are alr truncat scalar.
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	KX W	+ KCP		4047 •	+ KAL -	LP - KMO
	LCP' = LP	LCP = LCP + KCP	= LP + LCP + KPCP	LPCPI = KD	RR + LPCPI + KAL	= LAL + LP
	ū	D 11	LPCF = 1	LPC	LAL = LRR	LAP .
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3	LW = LW' + KW	The global scale of a virtual w as if it were accessed from RAM through Scaler #1. Here, LW is the global scale of w as stored in RAM and KW = KWH - KPO is the effective local scale, where KWH is the sensed hardware scale limited to 8 bits of upshift and KWO = KTl is the effective 1-bit truncation from 17 to 16 bits. An inhibit command is required.
ਰ । ਸ਼ ।	LAP > LW LW' = LW	The global scale of the updated 17-bit w is identical to that of the virtual maximally upshifted version. Following this decision, w is first locally scaled by Scaler #1 to w and p is downshifted by LAP - LW before combining at the AAU.
	LAP < LW LW' = LAP	Vector op is left alone. Considering that w in RAM could be shifted up by KWH, and that it can independently be shifted down by 7 bits, Scaler #1 is commanded to shift by KWH + LAP - LW. If downshift exceeds KWH + 7 the process is terminated. Note that at iteration #1 when w = 0, LW = LAP, arbitrarily. Also, if the process goes into the last iteration, the computation of w is an appropriate exit point.
g	LCP = LCP + KCP	As previously described.
ರೈಶ	LACP = LAL + LCP - KM0	Similar to op.
1/ <u>r</u> ²	LRRI = KD - LRR	Similar to 1/(p,Cp).

દા	LR = LR" + KR	The global scale of a virtual r as if it were accessed from RAM with maximum upshift through Scaler #1. Here, LR is the global scale of r in RAM and KR = KRH - KRO is the effective local scale, where KRH is the sensed hardware scale limited to 8 bits of upshift and KRO = KTI is the effective 1-bit truncation from 17 to 15 bits. An inhibit command is required.
do - 1 = 1	LACP > LR LR = LR	Similar to w-update. First, r is locally scaled by Scaler #1 and αCp shifted down by LACP - LR before combining at the AAU.
	LACP < LR LR' = LACP	Similar to w-update with corresponding stopping condition. Leaving aCp alone, r is shifted by KWH + LACP - LR before combining at the AAU. If downshift exceeds KWH + 7, the process is terminated.
ыl	LR = LR + KR	As described previously.
<u> </u>	LRR = LR + LR + KRR - KM	As described previously. Note that this quantity is computed simultaneously with the reciprocal of the previous $\ \underline{r}\ ^2$ so as to compute β by means of the real multiplier.
æ	LBET = LRR + LRRI + KBET - KMO	Similar to α .
ы	LP = LP' + KP	As described previously,
ವ ರ	LBP = LBET + LP - KMO	Similar to dp.

Global scale of maximally-upshifted virtual r.	Similar to w-update. First, r is locally scaled by Scaler #1 and Bp is shifted down by LBP - LR before combining at the AAU.	Similar to w-update with corresponding stopping condition. Leaving Bp alone, r is shifted by KRH + LBP - LR before combining at the AAU. If downshift exceeds KWH + 7, the process is terminated.	Signal Combiner Stage Postscaling	Weighted sum of auxiliary signals. Since the global scales for the auxiliary signal vector, s, and that of the main signal, s ₀ , may be arbitrarily taken to be zero, the global scale of s ₁ w is that of w; namely, LW. Here, NBW is the desired bit-resolution for w at the combiner stage; NBP is the processor word length.	Postscaled weighted sum of auxiliary signals prior to direct addition to the main signal.	combined signal.
LR = LR' + KR	LBP > LR LP' = LR	LBP < LR LR' = LBF	Signa	LSW = LW' = LW + KWF + NBW - NBP	TSW = 0	LSC = 0
2	2 + 1 = 2d			3 l	$(\underline{s}^{T_{W}})' = 2^{-LW} \underline{s}^{W}$	S = (x x x x x x x x x x

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4.0 COMPUTER EMULATION

A FORTRAN IV program has been written for the purpose of evaluating the adaptive fixed-point implementation of the BCR process via a precise emulation. To aid the explanation of the computer emulation program, BCRM, a numerical example is included which illustrates the BCR arithmetic activity in full detail. Finally, the fixed-point performance is compared with that of a 32-bit single-precision floating-point, which consistitutes a reference.

4.1 BCR Emulation Program - BCRM

The BCRM program is of modular construction similar to that of programs SIGGEN, BCRS and BCRP already described in Project Memorandum 8512-04. Being closely related to the floating-point simulation program, BCRS, the present BCRM program uses output data generated by SIGGEN, in a similar way. Essential aspects of BCRM are discussed below. The benchtest example used in Project Memorandum 8512-04 provides a means of describing BCRM in some detail. Results from other examples are included.

4.1.1 Input Data File - BCRM:D

The input data file, BCRM:D, for the BCR emulation program, BCRM, is listed in Table 4-1. It consists of a header file, BCRM:DO, which bears a resemblance to the header file, BCRS:DO, of BCRS:D. In fact, it differs only in that it contains a number of emulation parameters that pertain to the present program. The remaining portion of BCRM:D is the signal generation output file, SIGCEN:O, with all optional output suppressed.

As described in Project Memorandum 8512-04 for the case of BCRS:D, the BCRM:DO header of BCRM:D will require appropriate editing according to the SIGGEN:O used.

4.1.2 BCRM Program Structure

Just as the previous programs described, BCRM has a linear structure when considered on a major modular level. Physically, this implies that any module can be replaced without affecting any other module, as long as the interface is maintained. Procedurally, this implies that each branch of a program is executed before proceeding to the next in a top-down fashion, without backtracking and recursion. Such a structure is shown by the tree diagram of Figure 4-1.

In the tree diagram, the named blocks correspond to subprograms or modules by the same name, and the lines connecting them show their relationship. These lines also show the order of execution of the program, but not in the sense of a flow diagram, since no arrows are assigned to show the direction of flow. Starting at the top, the main (sub) program is seen to reference the executive subprogram, BCRMSET. It, in turn, uses the general

Table 4-1. Input Data File for BCR Emulation Frogram, BCRM: D Benchtest Example (See Figure 2-2, PM 8512-04)

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48834	.30318	12398	.22782	.61549	.29267	.28063	.30504
47300	-,08395	933	404	27158	.33822	886	.21674
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.76491	02179	.61187	10926	.60848	.28806		09097
.31446	.02369	35141	.16868	53609	.46701	04419	.31528
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.10807	61208	.48876	666	42084	.16529	26779	13871
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97474	.28751	27616	.24423	24091	.22343	30947	.16292
08795	02728	29755	.0007	45309	-,39201	63687	.13347
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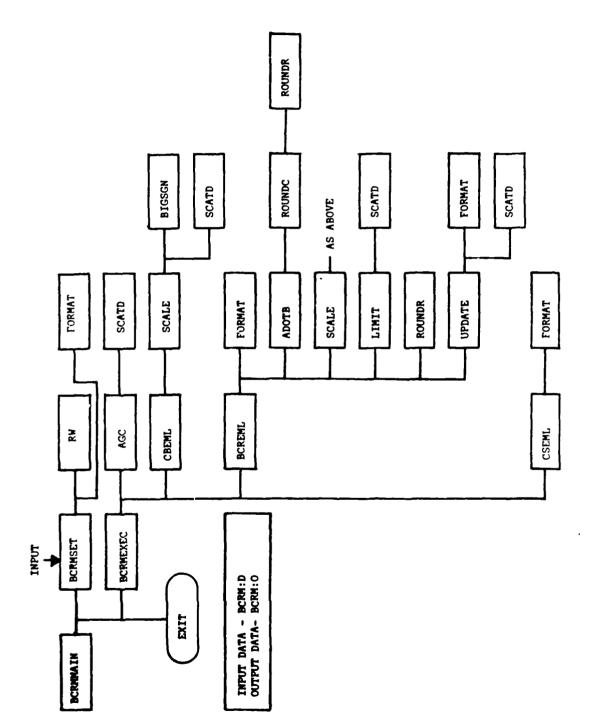
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05444	.13452	.07886	.14670	.10642	,18723	25	.06106
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.08469	0	-,45162	.43556	60672	.22376	.52855	
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13781	-	.26768	23405	21584	.11663	28070	~
13078	06747	577	.25729	.05354	08949	.02853	-,12514
13186	0	.09489	02	.12508	-,13571	.15364	~
-,21955	0	15048	.09321	16307	16264	-,37372	.23197
.01814	~	.26797	21060	04088	.05573	33448	.31802
-,17906	.12709	.09810	-,19682	06110	06102	49374	.41082
49855	**02**	07721	.00836	.23598	-,19245	.20013	-,16858
.07728	09084	.28895	29244	.21472	17014	16661	.10609
21063	0	17727	.14133	37081	.41300	044	.30951
.19766	24299	.37754	36810	-,30777	.20201	20702	,22364
.32705	24216	.25794	28607	-,35328	.16801	07539	.04373
08686	.21189	23436	.29481	37201	011	.03077	.05726
122	.14949	m	.03116	-,38935	404	11	.14987
. 12903	04933	33737	.31059	26064	.28383	73	.28123
538	.23941	29183	.21894	.02728	392	453	.08896
.55285	-, 39874	,35714	22750	605	634	.35608	29137
.32431	-,38152	.22754	17236	54062	682	222	.18842
50683	.42798	71107	.61984	87153	.71631	734	.24541
-,35185	.31092	20023	.17013	.11499	17318	33096	36196
.59618	44777	.04543	.03237	11078	055	10588	.06664
61690	.50981	11093	.05577	.29847	-,30015	.15461	26520
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.03464	03712	.07825	-,12736	.43991	42871	'n	04842
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13175	15	19421	.10610	39669	.28910	54147	.39412
-,19048	.15429	-,17685	.14169	.06323	09104	12121.	04268



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Figure 4-1. Tree Diagram of the BCR Emulation Program, BCRM

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subprogram, RW, to input data. Several calls are made to RW before all the input is completed, and then control returns to BCRMMAIN via BCRMSET. This completes one major branch of the structure.

The next major branch is accessed by calling the other executive subprogram, BCRMEXEC, which actually directs the BCR emulation via four dedicated subprograms. The first subprogram, AGC, provides the proper gain needed for sampling the main and auxiliary signals at desired bit levels with maximum resolution. The second subprogram, CBEML, heads the branch which is dedicated to computing and scaling the covariance matrix and forcing vector, C and b, respectively. Local bit-shifting and truncations are provided here to yield quantities C and b which are block-scaled to the resolution designated for the BCR processor. The third branch headed by BCREML actually executes the BCR emulation. The adaptive weight vector produced by BCREML is used in the final branch headed by CSEML where the optimal combined signal is computed. The evaluation of the power suppression achieved also takes place here.

After this last branch is complete, control again returns to BCPMMAIN, and the execution terminates via a call to EXIT. Functional descriptions of each module comprising BCRM is given in Table 4-2.

4.1.3 Source Modules

The BCRM source program consists of all the subprograms whose names are shown in the tree diagram of Figure 4-1. A complete list of these subprograms appears in Table 4-3 in the same order in which they are called. Each subprogram has a name which is identical to the subroutines or function name for which it stands. A short functional description of the program—module, dates of origin and revision, and the author's names precede the definition of the interface. It starts with input and output data identification, is followed by name and description of entry points and ends with the list of down-stream references to subroutines, functions and entries.

All the executive subprograms share data through a set of common statements. The major dedicated subprograms are conveniently accessed through a minimum set of common statements. In contrast to this, the minor dedicated subprograms and the general subprograms are accessed through a minimum set of arguments of a call statement. The purpose in each case was to enhance clarity, efficiency, and versatility.

4.1.4 Binary Modules

The individual source modules comprising BCRM are usually compiled separately as a matter of convenience. For every source module a corresponding

Note that the module RW used here is much more general than that used in Project Memorandum 8512-04 for programs SIGGEN, BCRS and BCRP. In fact, it accommodates calls previously made to RWIRC and does much more as should be evident upon a close examination. What is important is the fact that calls made to previous RW may also be made validly to its present version.

Figure 4-2. Functional Description of Program Modules Comprising BCRM

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		FUNCTIONAL DESCRIPTION OF BCRM PROGRAM MODULES
BCRMMAIN	•	MAIN EXECUTIVE PROGRAM. IT CALLS OTHER EXECUTIVE SUBPROGRAMS WHICH TOGETHER PERFORM THE BCR EMULATION.
BCQMSET	•	EXECUTIVE SURPROGRAM. IT IS DESIGNED TO READ FROM THE INPUT DATA FILE, RCRMID, USING THE GENERAL INPUT AND DUTPUT SURROUTINE, RW. IN ACCORDANCE TO PRESET FORMAT. ALL DATA ARE MADE AVAILABLE TO APPROPRIATE SURROUTINES THROUGH COMMON BLOCKS.
3	•	GENERAL SUBPROGRAM. THIS INPUT/OUTPUT SUBPROGRAM IS DESIGNED TO PEAD. WRITE OR SKIP LINES OF TFXT.
ACRMEXEC	•	EXECUTIVE SURPROGRAM. IT DIRECTS THE BCR EMULATION PROCESS BY CALLING FOUR DEDICATED SURPROGRAMS IN THE PROPER SEQUENCE. MAKING DATA AVAILABLE TO EACH AS NECESSARY.
₽ 6C	•	DEDICATED SURPROGRAM. IT IS DESIGNED TO DENORMALIZE THE MAIN AND AUXILIARY PORT SIGNALS USING THE SUPPLIED CONSTANT. AND TO SUBSEQUENTLY SCALE THEM IN SUCH A WAY THAT THEIR LARGEST ELEMENT IS A LEFT-JUSTIFIED WORD OF A GIVEN NUMBER OF BITS.
SCATD	•	GENERAL SUBPROGRAM. IT IS DESIGNED TO SCALE A REAL OR COMPLEX VECTOR USING THE SUPPLIED RIT-SHIFT. THEN TO TRUNCATE THE RESULT ACCORDING TO 2:S COMPLEMENT ARITHMETIC.
CREML	•	DEDICATED SURPROGRAM. IT IS DESIGNED TO COMPUTE THE COVARIANCE OF A BATCH OF AUXILIARY PORT SIGNALS, AND THE CROSS CORRELATION VECTOR OF THE AUXILIARY AND THE MAIN PORT SIGNALS. THE COVARIANCE MATRIX AND THE CROSS CORRELATION OR FORCING VECTOR ARE THEN INDIVIDUALLY SCALED TO A SIZE DETERMINED BY THE PROCESSUR WORD.
SCALE	•	GENERAL SUBPROGRAM. IT IS DESTGNED TO SCALE REAL OR COMPLEX VECTORS BY SHIFTING ALL COMPONENT WORDS BY A NUMHER OF HITS THAT WILL LFFT-JUSTIFY THE LAHGEST-MAGNITHUE WORD.

BIGSGN	•	GENERAL SUBPROGRAM. IT IS DESIGNED TO SEARCH A REAL. OR COMPLEX Vector to find the element which has the largest absolute value. This value and its sign are returned.
BCREML	•	DEDICATED SUBPROGRAM. IT IS DESIGNED TO EMULATE. THE ARITHMETIC ACTIVITY OF THE PROCESSOR WHICH PERFORMS THE ACTUAL BCR. PROCESS. THIS TASK IS ACCOMPLISHED WITH THE AID OF OTHER DEDICATED AND GENERAL SUBPROGRAMS. THE OUTPUT OF THE SUBPROGRAM IS A SCALED VALUE OF THE ADAPTIVE WEIGHT VECTOR.
FORMAT	•	GENERAL SUBPROGRAM. IT IS DESIGNED TO OUTPUT DATA IN A VERSATILE AND STANDARDIZED FORMAT.
ADOTR	•	GENERAL SUBPROGRAM. IT IS DESIGNED TO PERFORM THE DOT PRODUCT OF TWO COMPLEX VECTORS WITH THE OPTION OF USING THE CONJUGATE OF THE FIRST VECTOR. EACH INDIVIDUAL MULTIPLICATION RESULT IS ROUNDED AND SURSEQUENTLY TRUNCATED ACCORDING TO THE ACTUAL OPERATION OF THE MULTIPLIER CHIP USED.
ROUNDC	•	GENERAL SUBPROGRAM. IT IS DESIGNED TO MULTIPLY TWO COMPLEX NUMBERS. AND TO ROUND OFF THE RESULT.
ROUNDR	•	GENERAL SUBPROGRAM. IT IS DESIGNED TO MULTIPLY TWO REAL NUMBERS. And to round off the Result.
LIMIT	•	DEDICATED SURPROGRAM. IT IS DESIGNED TO PROVIDE THE ALGORITHM WHICH REPRESENTS HARDWAKE LIMITS. THESE LIMITS DEFINE THE SHIFT-ING RANGE.
UPDATE	•	DEDICATED SURPROGRAM. IT IS DESIGNED TO CARRY OUT THE UPDATING OF W. P. AND P VECTORS WHILE IT EXERCISES SCALE EQUALIZATION WITHIN HAKDWARE LIMITS.
CSEML	•	DEDICATED SURPROGRAM. IT IS DESIGNED TO PRODUCE THE COMBINED SIGNAL, AND THE WEIGHTED SUM OF THE AUXILIARY PORT SIGNALS ADDED TO THE MAIN. THE COMBINED POWER SUPPRESSION IS ALSO COMPUTED HERE.

Table 4-3. FORTRAN Listing or Source Modules Comprising the BCR Emulation Program, BCRM

HUNNHUNKUNKUNKUNKUNTITITITITITITITITITITITITITITITITITITI	DIGITAL ADAPTIVE ARRAY PROCESSING	USING BATCH COVARIANCE RELAXATION	PROGRAM : BCRMMAIN:S URIGINAL : AUGUST 15, 1979	REVISION : MAPCH 11. 1981	PREPARED BY : S.M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP	MOTOROLA GOVERNMENT ELECTRONICS DIV TEMPE, ARIZONA 85282	HERBREARBREARBREARBREARBREARBREARBREARBR	CALL EXIT
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PROGRAM : BCRNSETIS ORIGINAL : JULY 23, 1980 REVISION : HARCH 25, 1981 PREPARED BY : S. M. DANIEL & I. KERTESZ RADAR SYSTEMS AMALYSIS GROUP MOTOROLA 6002RAMICS DIV. TEMPE, ARIZONA 85282 INPUT : DATA FILE BCRM:0 CHARY POINTS : BCRMSET PROGRAMS CALLED : SUBROUTIME FUNCTION ENTRY RW RWI COMMON CALLED : SUBROUTIME FUNCTION ENTRY RW RWI COMMON CALLED : SUBROUTIME FUNCTION ENTRY RW RW RWI COMMON CALLED : SUBROUTIME FUNCTION ENTRY RW RW RW RW RW RW RW RW RW RW RW RW RW R		SPECIFICATION OF SYSTEM PARAMETERS MAIN-PORT AND AUXILIARY BASEBAND SIGNALS	SPECIF MAIN-PORT	ICATI	ON OF	ON OF SYST	EN P.	SPECIFICATION OF SYSTEM PARAMETERS N-PORT AND AUXILIARY BASEBAND SIGNALS	ALS	
PREPAR INPUT 1 D OUTPUT 1 D OUTPUT 1 D OUTPUT 1 D COMPLEX S1.50 COMMON /BCR1/		PRO	GRAM	-	90	AMSET 1	Į.			
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INPUT 1 DOUTPUT										
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INPUT 1 DOUTPUT						TOROLA	60V	ERNMENT E	LECTRO	
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COMMON /BCRO/ IMSO+IMS1+IMSOF+IMSIF+IWCB+IDP(20) COMMON /BCR1/ SO(256)+S1(256+20)+NSX+NSITSO+NBITS1+SOMA) COMMON /BCR2/ ISW(20)+NX+IMO+NPM1+ITERX+NBITSP+NRITSW -+KM+KMO+KD+KT1+KT3+LIM1+LIM2+LRRT DIMENSION ISC(20)+ISP(20)+WARNIN(20)				# # # #	7 14 17 18	Ä H H H	Ä M M		H H H H	
COMMON /BCR1/ SO(256).S1(256.20).NSX.NS.NBITSO.NBITS1.SOMA) COMMON /BCR2/ ISW(20).NWX.IWO.NPM1.ITERX.NBITSP.NRITSWKM.KMO.KD.KT1.KT3.LIM1.LIM2.LRRT OTMENSION ISC(20).ISP(20).WARNIN(20) DATA WARNIN/		COMMON /BCR		. INS	I . IWS	P. IVS	16,11	WCB . 10P (2	6	
COMMON /BCR2/ ISW(20).NWX.IWO.NPM].ITERX.NBITSP.NRITSWKM.KMO.KD.KT].KT3.LIM].LIM2.LRRT OTMENSION ISC(20).ISP(20).WARNIN(20) DATA WARNIN/		COMMON /BCR		56),	1 (25	5.201.1	NSX .	NS.NBITS0	.NBITS	1.50MA)
KM-KMO-KD-KT1-KT3-LIM1-LIM2-LRRT OTMENSION ISC(20)-ISP(20)-WARNIN(20) DATA WARNIN/		COMMON /BCR	2/ ISM	20) .1	WX . I'	MON.OP	1.11	ERX.NBITS	P.NRIT	AS.
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DATA WARNIN/		DIMENSION I	SC (20) •	1SP (2	M. (0	PNINC:	50)			
		DATA WARNIN	_							

	_		REI	CALL PWI(IWSI)	RWICI	PAI	RWICI	DESERTER OF DESERTABLE STREETS OF TH		RW (3		_	MA	REI	OX	RESIDENTIAL STORES AND ADDITION OF STATEMENT OF STREET STORES AND ADDITIONAL STORES AND		RW (5				CALL RWI (NBW)	NBITSO=NBO=1	NRITSI=NBI-1	NPITSP=NBP=1	S	3 (B	* 0	7 . K		A .	T. 1	•	•	CALL RWI(NPOL)
U	U (ر					•	ن د	، ر	د					•	ں د	ď	•															(د	
*	6 0.	• 0 •	8	4 0.	50.	51.	52.		• u	90.00	57.	58.	59.	60	61.	9 9 9	9	65.	99	67.	68.	69	70.	71.	72.	73.		.0,	• :		6	80.		93.	95°	86.

CALL RW (NPOL+11)	CALL RWICHMLS) CALL RWICHMLS) ICSUM=0 DO 10 IC=1,NCHNLS 0 ICSUM=ICSUM+1SC(IC) CALL RW(++0+1CSUM)		NPMI=NPORTS=1 CALL RWIV(NPMI.ISP) IPSUM=0 DO 20 IP=1.NPMI IPIW=ISP(IP)*ISW(IP) IF(IPIW-EQ.ISW(IP)) GOTO 20 CALL FORMAT(WARNIN.80) STOP	CALL RW(7*(IPSUM+1)) CALL RW(7*(IPSUM+1)) READ MAIN AND AUXILIARY BASEBAND SIGNALS Min Tall		DENORMALIZE SO DO 30 IS=1.NS DO 50 (IS) #SMAX*SO(IS) SOMAX*SMAX
o c	00 2	UUU		လို ပပပ	UUU -	ပပပ ကီ ပ
94.	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	99. 99. 100. 101.	1004. 1005. 1004. 1009.	1113. 1114.	1117. 1118. 1120. 121.	124. 125. 126. 128.

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U	READ ONLY THOSE OF THE DESIGNATED PORTS WHICH ARE SELECTED BY ISW
00	MULTE1 IF(IMS1.EQ.0) IIPE0 NROWSE(NS-1)/4 SIMAX=0 DO 50 IPE1.NPW IF(ISW(IP).EQ. CALL RW(-9-NRC GOTO 50 IIPEIIP+1 INPEIIP+1
: 	READ SI AND WRITE IT ONLY IF IWSIE!
;	CALL RW(7*MULT) CALL RWRV(NS2*MULT,S1(1,IIP),SMAX)
i 500	DENORMALIZE SI
	DO 40 IS=1,NS SI(IS-IIP)=SMAX+SI(IS-IIP) IF(SMAX.GT.SIMAX) SIMAX=SMAX CONTINUE NPMI=IIP CALL RW(1)
i u	RETURN

		SUBROUTINE RW(NV.IV.RV.AR14)	'• IV•RV•A	
		SKIPPING	GENERAL SPECIFIE	READ/WRITE ROUTINE FOR) NUMBER OF LINES OF INPUT
	vvvv	PROGRAM ORIGINAL REVISION		RW:S APRIL 15, 1978 MARCH 17, 1981
RAIS APRIL 15.	, .	PREPAREC	. 78	Q Z
PROGRAM : RW:S ORIGINAL : APRIL 15, 1978 REVISION : MARCH 17, 1981 REVISION : S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS DIV TEMPE, ARIZONA 85282	I I I I I I I I I I I I I I I I I I I	> Z		1 & -
PROGRAM : RW:S ORIGINAL : APRIL 15, 1978 REVISION : MARCH 17, 1981 RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS DIV TEMPE, ARIZONA 85282 INPUT : NV - NUMBER OF COMMENT LINES TO READ AND WRITE: THE NUMBER OF LINES TO SKIP.		Q V		COMPLEX SCALAR REAL SCALAR INTEGER SCALAR INTEGER VECTOR REAL OR COMPLEX VECTOR REAL SCALAR EXCLUSIVE OF CX & IX INTEGER SCALAR EXCLUSIVE OF CX & RX 56 - CHARACTER COMMENT
PROGRAM : RW:S ORIGINAL : APRIL 15, 1978 REVISION : MARCH 17, 1981 PREPARED 87 : S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS DIV TEMPE, ARIZONA 85282 INPUT NV - NUMBER OF COMMENT LINES TO READ AND WRITE, THE NUMBER OF LINES TO SKIP. CX - COMPLEX SCALAR RX - REAL SCALAR IX - INTEGER SCALAR IX - INTEGER SCALAR IX - REAL SCALAR IX - REAL SCALAR IX - REAL SCALAR IX - REAL SCALAR IX - REAL SCALAR IX - REAL SCALAR IX - REAL SCALAR IX - REAL SCALAR EXCLUSIVE OF CX & RX ANIA - S6 - CHARACTER COMMENT	C LOCAL	ARRAYS CONSTANT VARIABLE	ARRAYS ARRAYS	1 IV. RV. AR14 1 LC12. LC20 1 LR12. LR12. LR20
PROGRAM : RW:S ORIGINAL : APRIL 15. 1978 REVISION : MARCH 17. 1981 RADAR SYSTEMS ANALYSIS GROUF RADAR SYSTEMS ANALYSIS GROUF RADAR SYSTEMS ANALYSIS GROUF RADAR SYSTEMS ANALYSIS GROUF RADAR SYSTEMS ANALYSIS GROUF RADAR SYSTEMS ANALYSIS GROUF RADAR SYSTEMS ANALYSIS GROUF RADAR SYSTEMS ANALYSIS GROUF RADAR SYSTEMS ANALYSIS TO F RADAR SYSTEMS ANALYSIS TO	C ENTRY	y POINTS		RW - READ AND WRITE NV COMMENT LINES IF NVCO, -NV LINES ARE SKIPPED

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ENTRY RWI
                                                                                                                                                                                                                                                                                                                  READ AND WRITE NV COMMENTS. IF NV<0. SKIP -NV LINES! ENTRY RW
            - READ AND WRITE REAL SCALAR
- WRITE REAL SCALAR
- READ AND WRITE COMPLEX SCALAR
                                              - WRITE COMPLEX SCALAR
- READ AND WRITE INTEGER VECTOR
- READ AND/OR WRITE REAL OR
                                                                                              - WRITE REAL OR COMPLEX VECTOR
                                                                                                                                                                                                                                                                                                                                 DIMENSION IV(1), RV(1), AR14(14)

DIMENSION LC12(12), LC20(20), LR12(12), LR14(14), LR20(20)

DATA LC12/4** ** ** NORMALIZATION CONSTANT : */
- WRITE INTEGER SCALAR
                                                                                   COMPLEX VECTOR
                                                                       RWRV
                                                              Z = 2
                                                                                                                                                                                                                                                                                                                                                                                                                                                               READ AND WRITE INTEGER DATA :
                                                                                                                        NONE
                                    SEC
SEC
              Q B Q
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                                                                                                                                                                                                                                                                                                                                 DATA LC20/ --- 1,19* ---- 1/
                                                                                                                                                                                                                                FORMAT (1444,2X,2(F10.5))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  READ(105,100) LR14,IX
WRITE(108,100) LR14,IX
                                                                                                                                                                                                                                                                                                                                                                                                                                                       IF (NV.LE.0) GOTO 1000
                                                                                                                                                                                                                                                        FORMAT (1444,4X,1012)
                                                                                                                                                                                                                                                                                                                                                                             WRITE(108,400) LR20
                                                                                                                       SUBROUTINES CALLED
                                                                                                                                                                                                                                                                                                                                                                 READ(105,400) LR20
                                                                                                                                                                                                                     FORMAT (1444,F12.5)
                                                                                                                                                                                                                                                                    FORMAT (1244,E13.6)
                                                                                                                                                                                                         FORMAT (1444.112)
                                                                                                                                                                                                                                                                              FORMAT (8F10.5)
                                                                                                                                                                                                                                                                                                                                                                                                                              READ (105.800)
                                                                                                                                                                                                                                                                                                                                                                                                                 DO 20 I=1.NVP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       ENTRY RWI (IX)
                                                                                                                                                                                                                                                                                                                                                      DO 10 I=1.NV
                                                                                                                                                                                                                                            FORMAT (2044)
                                                                                                                                               COMPLEX CX
                                                                                                                                                                                                                                                                                             FORMAT (1X)
                                                                                                                                                                                                                                                                                                                                                                                                       NVD8-NV
                                                                                                                                                                                                                                                                                                                                                                                         RETURN
                                                                                                                                                                                                                                                                                                                                                                                                                                         RETURN
                                                                                                                                                                                                                                                                                                                                                                                                     1000
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•	RETURN	
	INTEGER	ENTRY WI
، د	ENTRY WI(AR14.1X) WRITE(108.100) AR14.1X RETURN	
i 	READ AND WRITE REAL DATA :	ENTRY REE
i J	ENTRY RWR(RX) READ(105,200) LR14,RX WRITE(108,200) LR14,RX RETURN	
i	WRITE REAL DATA :	ENTRY ER
i ب د	ENTRY WR(AR14.RX) WRITE(108.200) AR14.RX RETURN	
i 	AND WRIT	ENTRY REC
i ب د	ENTRY RWC(CX) READ(105,300) LR14,CX WRITE(108,300) LR14,CX RETURN	
		ENTRY WC
	j — — —	
	READ AND WRITE INTEGER	ENTRY RUIV
2000	ENTRY RWIV(NV.IV) N1=1 N2=10 READ (105.500) LP14.(IV(I).I=N1.N2) WRITE(108.500) LR14.(IV(I).I=N1.N2) N1=N1.10	

> 2	· · · · · · · · · · · · · · · · · · ·			ENTRY WRV		
READ AND WRITE (ONLY IF NV.GE.O) REAL VECTOR :	ENTRY RWRV (NV-RV-RMAX) ANV#1485 (NV)	READ (105,600) LR12,RMAX READ (105,400) LR20	READ (105,700) (RV(I),I=1,ANV) IF(NV.LE.0) RETURN	WRITE REAL VECTOR:	ENTRY WRV(NV,RV,RMAX) ANVEIABS(NV) WRITE(108,600) LC12,RMAX WRITE(108,400) LC20 WRITE(108,700) (RV(I),I=1,ANV) RETIPN	
ى ن ر	,		c	ى ن ر	,	
	READ AND WRITE (ONLY IF NV.GE.O) REAL VECTOR :	READ AND WRITE (ONLY IF NV.GE.O) REAL VECTOR : ENTRY RWRV(NV.RV.RMAX)	READ AND WRITE(ONLY IF NV.GE.O) REAL VECTOR : ENTRY RWRV(NV.RV.RMAX) ANV=IABS(NV) READ (105.600) LR12.RMAX READ (105.400) LR20	READ AND WRITE (ONLY IF NV.GE.O) REAL VECTOR : ENTRY RWRV (NV.RV.RMAX) ANV=IABS (NV) READ (105.600) LR12.RMAX READ (105.400) LR20 READ (105.700) (RV(I).I=1.ANV) IF (NV.LE.O) RETURN	READ AND WRITE(ONLY IF NV.GE.O) REAL VECTOR; ENTRY RWRV(NV.RV.RMAX) ANV=IABS(NV) READ (105.600) LR12.RMAX READ (105.400) LR20 READ (105.700) (RV(I).I=1.ANV) IF(NV.LE.O) RETURN WRITE REAL VECTOR;	READ AND WRITE (ONLY IF NV.GE.O) REAL VECTOR : ENTRY RWRV(NV.RWAX) ANV=1ABS(NV) READ (105.400) LR12.RMAX READ (105.400) LR20 READ (105.400) LR20 READ (105.400) LR20 READ (105.400) LR20 READ (105.400) LR20 READ (105.400) LR20 WRITE REAL VECTOR: ENTRY WRV(NV.RV.RMAX) ANV=1ABS(NV) WRITE(108.400) LC12.RMAX WRITE(108.400) LC20 WRITE(108.700) (RV(I).I=1.ANV) RETIJRN

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		PROGRAM ORIGINAL REVISION		FORMATIS APRI 15. 1978 MARCH 17. 1981
		PREPARED BY	••	ERTESZ S GROUP LECTRONICS DIV.
		I CABEL CX CX RX IX NX NY IFIELD		IDENTIFYING LABEL OR FULL LINE COMMENT COMPLEX-VALUED ARRAY REAL-VALUED ARRAY INTEGER-VALUED ARRAY ARRAY DIMENSIONALITY FIELD OPTION FUR FORMR AND FORMC 5 : PRINT WITH FIO.5 FORMAT 1 : PRINT WITH FIO.1
,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	₹ 4 4 7 8	POINTS	•	FORMAT - FOR COMMENT LINE OF 0-120 CHARACTERS FORMI - FOH INTEGER TYPE FORMC - FOR COMPLEX TYPE FORMC - FOH GENERAL TYPE FORMG - FOH GENERAL TYPE EXPONENTIAL NOTATION MAY BE REQUIRED
, u u	SUBROUT	SUBROUTINES CALLED	••	NONE
ပ	COMPLEX DIMENSI	BREEFFRESSELLESSELLESTERSELSESSELLESSE COMPLEX CX DIMENSION LABEL(30).CX(1).RX(1).IX(1)	E S C C C C C C C C C C C C C C C C C C	ROBBERTORES REPRESENTANT FOR THE STANDARD SOUTH STANDARD SOUTH STANDARD SOUTH
200		FORMAT (3044) FORMAT (744.8110/(28X.8110))	.811	
W 4 A		FORMAT(/744/) FORMAT(744.8F10.5/(28X.8F10.5)) FORMAT(744.8F10.1/(28X.8F10.1))	6 X 4 39	F10.5)

4.6	009	FORMAT (5A4,8G11.5/(20X,8G11.5))	
9	000	PRINT A LINE OF COMMENT OF 0 TO 120 CHARACTERS :	ENTRY FORMAT
0.00	ا ب ر	NB=NX/4 WRITE(108.100) (LABEL(I),I=1,NB) RETURN	
52.		PRINT INTEGER ARHAY :	ENTRY FORMI
	i 		
58.			ENTRY FORMR
60 62 63	: ب د	ENTRY FORMR(LABEL,RX,NX,IFIELD) IF(IFIELD,EQ.1) #RITE(108,500) (LABEL(I),I=1,7),(RX(I),I=1,NX) IF(IFIELD,NE.1) #RITE(108,400) (LABEL(I),I=1,7),(RX(I),I=1,NX) RETURN	• [= 1 • NX) • [= 1 • NX)
65.		PRINT COMPLEX ARRAY :	ENTRY FORMC
6 6 7 6 6 7 6 6 7 6 6 7 6 6 7 6 6 7 6 7	i	ENTRY FORMC(LABEL,CX,NX,IFIELD) IF(IFIELD,EQ,1) WRITE(108,500) (LABEL(I),I=1,7),(CX(I),I=1,NX) IF(IFIELD,NE,1) WRITE(108,400) (LABEL(I),I=1,7),(CX(I),I=1,NX) RETURN	• I = I • XX)
72.		PRINT ANY DATA TYPE WHEN EXPONENTIAL NOTATION MAY BE F FOR COMPLEX DATA USE NX=2+NX :	REQUIRED. Entry Formg
75. 76. 77.	i J	, -	

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	BCR EMULATION EXECUTION PROGRAM	BCRMEXEC:S JANUARY 15. MARCH 19.	S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS DIV. TEMPE, ARIZONA 85282	BCAMEXEC	SUBROUTINE AGC CBEML BCREME	CSEML	
	EMULATIO	40 60 00		- - - -	-	7 0 3 1 0	
SUBROUTINE BCRMEXEC	MUNICALITY OF THE STATE OF THE	PROGRAM ORIGINAL REVISION	PREPARED	ENTRY POINTS	PROGRAMS CALLED	CSEMI	CALL AGC CALL CBEML CALL BCREML CALL CSEML RETURN END
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OUTPUT : PROGRAMS CALL COMPLEX SO.S1 COMMON /BCRO/				
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OUTPUT : ENTRY POINTS PROGRAMS CALL COMPLEX SO.S1 COMMON /BCRO/	U	SZ	- NUMBER OF S	
SOUTPUT : ENTRY POINTS PROGRAMS CALL COMPLEX SO.S1 COMMON /BCRO/	U	NSX		BER OF SAMPLES IN SO
OUTPUT : ENTRY POINTS PROGRAMS CALL COMPLEX SO.S1 COMMON /BCRO/	U	20		IGNAL VECTOR
OUTPUT : ENTRY POINTS PROGRAMS CALL COMPLEX SO.S1 COMMON /BCRO/	U	S1		ORT SIGNAL VECTORS
OUTPUT : ENTRY POINTS PROGRAMS CALL COMPLEX SO.S1 COMMON /BCRO/	د د	SOMAX	U	OF 50
OUTPUT : ENTRY POINTS PROGRAMS CALL COMPLEX SO.S1 COMMON /BCRO/		SIMAX	- LARGEST ELE	6
OUTPUT : ENTRY POINTS PROGRAMS CALL COMPLEX SO.S1 COMMON /BCRO/	U	INSOF	- PRINT OPTIO	S0 (1 FOR
ENTRY POINTS PROGRAMS CALL COMPLEX SO.S1 COMMON /BCRO/	U	INSIF		FOR SI
ENTRY POINTS PROGRAMS CALL COMPLEX SO,S1 COMMON /BCRO/				
PROGRAMS CALL COMPLEX SO,S1 COMMON /BCRO/		-	- SCALED VERS	
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/8CR1/	COMMON	/8CR1/	+S1(5120)+NSX+N	S.NB1150.NB1151.50
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DIMENSION PAGE(30).LINE(30) DATA LINE/:',29*''/.PAGE/:]',29*''/		DENORMALIZE SO AND		DO 10 15=1.NS	S0(1S)=S0(1S)/S0MAX	CALL SCATU(NS2,NBITS0.S0)	-	FORMAT (PAG		FORMAT (LINE	t	FORMR (.	FORMI (•	CALL FORMC(* SO	CALL FORMAT (LINE.108)	NC=1	DO 30 IP=1,NPM1	NCP#NC+NSX-1	00 20 IS=NC.NCP	S1 (IS) #S1 (IS) /S1MAX	CALL SCATU(NS2,NBITS1,S1(NC))	-	FORMAT (PAG		FORMAT (LIN	CALL FORM C FOR C		FORMICE	TO MADE	CALL PURMATICINE . 108)			
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υu				MOTOROLA GOVERNMENT ELECTRONICS	. 10
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υ (PROV 1DE	C	DOWN-SHIFT	AND TRUNCATION:	ENTRY SCATU
د	(SN-) ++2#NOI	(-NS)		*	
	00 10 I	10 I=1.0X			
	IX=X(I)				
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	IF (IXO.GE.0)	GE.0) GOTO 10	01		•
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	IXOXIXO		?		
10	X(I) = IXO	· 0			
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ں ر	PROVIDE	PROVIDE UP-SHIFT	AND TRE	AND TRUNCATION:	ENTRY SCATU
ر	ENTRY S	ENTRY SCATU(NX+NS+X)	(X • 8		j 1 1 1 1
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DO 20 I=1.NX IX=X(I) • IUP X(I) = IX RETURN END

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	BAT	Y C0	BATCH COVARIANCE		MATRIX AND CROSS-CORVELATION VECTOR	S-COR-ELATION	+ VECTOR
ى ر <u>ى</u>	-	PROGRAM	I	••	CBEMLIS		
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o a	-	PREPARED	ED BY	••			253
		l			RADAR SYSTEMS	S ANALYSIS GROUP	2006 2007 2007 2007 2007 2007 2007 2007
U U					TEMPE ARIZONA	TEMPE, ARIZONA 85282	
ເ ບບ	TUPUT	5	50		MAIN PORT SI		
د	•	S)	51	•	-		SIGNALS
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ں					SIGNALS		
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٠ ن	PROGRAMS CALLED	S CALI	E0	••	SUBROUTINE	FUNCT ION	ENTRY
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ပ					•	ŧ	FORMC

COMMON /BCR2/ ISW(20),NWX,IWO,NPM1,ITERX,NBITSP,NBITSW -+KM,KMO*KD,KT1,KT3,LIM1;LIM2,LRRT COMMON /BCR3/ C(20,20),B(20),P(20),CP(20),X(400) -+W(20),ACP(20),AP(20),PR(20),KC,KB,LW DIMENSION LINE(30),PAGE(30) DATA LINE/		SCALE C AND 8 NX=0 DO 50 J=1.NPM1 DO 50 J=1.NPM1 NX=NX+1 X(NX)=C(I+J) CALL SCALE(X.NX+2.NBITSP.KC) NX=0 DO 50 J=1.NPM1 DO 50 J=1.NPM1 NX=NX+1	
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.,28)	1NBITSP-1.1.0)	*********	1,28)	1., NBITSP+1,1,0)	A CONTRACTOR	
MATRIX			• • • •			
CALL FORMAT(* BATCH COVARIANCE MATRIX *+28)	CALL FORMI (* NBITSP CALL FORMI (* KC	CALL FORMAT(LINE, 108)	CALL FORMAT(" FORCING VECTOR CALL FORMAT(LINE, 108)	CALL FORMIC NBITSP	CALL FORMCI'S	CALL FORMAT(LINE.108) Return
		U	•			
87. 88.		92.	94.	96. 97.	99.	99. 100.

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٠ ٠		SURROUTINE SCALE (X+NX+NB+NS)	.NX.NB	· NS)	
.			*****		
•	U	SCALING AND TRUNCATION OF	TRUNCA	TION OF REAL O	REAL OR COMPLEX VECTOR
5.	ပ		T0 G	TO GIVEN WORD-LENGTH	I -
•	ပ		I LI	WITH COMMON BIT-SHIFT	
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&	U (LARGEST-	MAGNIT	LARGEST-MAGNITUDE WORD IS LEFT-JUSTIFIED	FT-JUSTIFIED
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15.	ن ر				NAL YS
16.	U			MOTOROLA GOVE	MOTOROLA GOVERNMENT ELECTRONICS DIV.
17.	U			TEMPE. ARIZONA	
18.	FIGNI			VECTOR TO BE	TO DE SCALED
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• • • •	ى ر	₹ व) (5 6	ELEMENTS IN A DOTAL THREE DOOR
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24.	COUTPUT	UT : X	•	X SCALED AND	AND TRUNCATED
25.	U	SN	ŧ		OF TWO USED IN SCALING
26.	3		Ĭ		
27.	ENT D	ENTRY POINTS	••	SCALE	
	S PROG	PROGRAMS CALLED	•	SHAROUTINE	FUNCTION FINES
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43°	I X V X	LAGHEAHLANS (ANAA) Maxihooorr			

ا ن	
U U	SELECT DIRECTION OF THE BIT SHIFT
ا ب ر	IF (IABMAX-MAXI) 1000,3000,2000
: ວບເ	SHIFT UP
1000	DO 10 I#1.NB10 IARMAX#IARMAX#2 IF(IABMAX.GT.MAXI) GOTO 3000 NS=NS+1
	NEOD HILLS
2000	DO 20 I#1.NR IARMAX#IARMAX/2 NS#NS-1
20	AX.LE.MAXI) GO TO 3000
ا د د د	SCALE AND TRUNCATE X
3000	IF(NS.LT.0) CALL SCATD(NX.NS.X) IF(NS.GE.O) CALL SCATU(NX.NS.X) RETURN

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N m 4 W 4	FUNCTION BIGSGN(NX+X) C BEBRESSESSESSESSESSESSESSESSESSESSESSESSESS	FUNCTION BIGSGN(NX,X) **********************************
	202	5 27, 1981 11, 1981
112. 123. 134. 15.	C PREPARED BY 1 S. M. D. C RADAR S' C MOTOROLL C TEMPE.	
	INPUT : X - VECTOR NUMBER	TO BE SEARCHED OF ELEMENTS IN X
20. 21.	- OUTPUT 1 BIGSGN -	Z
23. C	C ENTRY POINTS : BIGSGN	
%. %. 	C PROGRAMS CALLED : NONE CABBERRARESERVERS CALLED	80 to 100
		HE LARGEST ELEMENT OF X
	•	

	ESTIMATION	b >	ESTIMATION OF THE ADAPTIVE WEIGHT VECTOR
		•	
	PROGRAM	-	15
	ORIGINAL REVISION		AUGUST 15. 1979 MARCH 25. 1981
		•	
,	PREPARED BY	••	S. M. DANIEL & I. KERTESZ
			RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS DIV. TEMPF. ARIZONA 85282
TIONI		•	13
	œ	•	
	•		MAIN AND AUXILIARY SIGNALS
	NSX	•	MAXIMUM NUMBER OF SIGNAL SAMPLES
	SN		
	XXX	•	NUMBER OF WEIGHT
	MDM	•	
	ΥC		OF BITS BY WHICH C WAS
	6 0	•	OF BITS BY WHIC
	NBITSP	•	OF BITS IN T
	MBITSH	•	BITS IN A W
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	Ž,	•	Z
	KT1	•	•
	X T M	•	3 - BIT TRUNCATIONS KRRO.KCPO.KPCPO
	LINI		ALLOWABLE
	LIMS	•	ALLOWABLE UP-SHIFT
	LRRT	ı	ALLOWED GLOBAL SCALE REDUCTION OF
	ITERX	•	
OUTPUT	3	•	WEIGHTING VECTOR
ENTRY POIN	ENTRY POINTS	-	BCREML
PROGR	PROGRAMS CALLED	••	INE FUNCTION

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COMMON /BCR1/ S0(256).S1(256.20).NSX.NS.NBITSO.NBITS1.SOMAX.S1MAX COMMON /BCR2/ ISW(20).NWX.IWO.NPM1.ITERX.NBITSP.NBITSW --KM.KMO.KD.KT1.KT3.LIM1.LIM2.LRRT COMMON /BCR3/ C(20.20).B(20).R(20).P(20).C(20).X(400)
                                                                    ADAPTIVE FIXED-POINT
                 SCALE
                                                UPDATE
                                                         ROUNDR
        FORMC
                                     LIMIT
FORMR
                             ADOTB
                                                                                                                                                           1 . V . NPSO . 1 )
                                                                                                                                               DATA LINE/! ---1,29*!---1/, PAGE/!]---1,29*!---1/
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                                                                             COMPLEX SO.SI.C.8.P.P.CP.W.X.ACP.AP.8P.CPCP.CRDR
                                                         ROUNDR
                                                                                                                           -. W (20) , ACP (20) , AP (20) , BP (20) , KC, KB.LW
                                                                                                                                                                                                                                                                                                                                                                                      -ARITHMETIC OF BCR PROCESSOR . 80)
                                               UPDATE
                  SCALE
ADOTB
                                     LIMIT
                                                                                                                                      DIMENSION LINE (30) , PAGE (30)
                                                                                                                                                                                                                                                                                                                                                                    CALL FORMAT (PAGE . 108)
                                                                                                                                                                                                                                                                                                                                                                                                 CALL FORMAT (LINE . 108)
                                                                                                                                                                                                                                                                                        KS01=NBITS0-NBITS1
                                                                                                                                                                   INITIALIZATION
                                                                                                                                                                               FOHMAT ( .
                                                                                                                                                                                                NAVANBITSW+1
                                                                                                                                                                                                                                                                                                                   NPM12=2*NPM1
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                                                                                                                                                                                                                                                           KAROSKIS
                                                                                                                                                                                                                                                                    KCP0=KT3
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Z Z • • X	1KB.NPM1.1) 1KB.1.0) 1KMF.1.0)	1 * 4 * 4 * 0 * 1)	1.,CRDR.1.1)	1., RDR.11.1) 1., KRRH.11.0) 1., KRR.11.0)		1',1TER,1,0)	I).P.NPMI.CP(I).KM,0) CP PMI2.NBITSP.KCP) PMI2.KCP.KCP0,LIMI.LIM2)
	01	FORMC(* * * * * * * * * * * * * * * * * * *	ADOTB (R.K.NPM) FORMC(* CRDR EAL (CRDR) SCALE (RDR,1,NB *LR*KRR-KM	FLRR FORMI(* KRRH FORMI(* KRR = KRRH - KRRO FORMI(* LRR = 2*LR + KRR FORMAT(LINE,108)	F ITERATION	CALL FORMAT(PAG CALL FORMI(* CALL FORMAT(LIN COMPUTATION OF	1 = 1.NPM1 ADOTB (C(1.FORMC(*) FORMC(*) SCALE (CP.N

1CP.NPM1.1) 1KCPH.1.0) 1KCP.1.0)			**•CPCP*1*1)			11.1.000.1	* • KPCPH• 1 • 0		,	(8)	(S C C C C C C C C C C C C C C C C C C	*****28)	1. * KPCPI.1.0)	: • • KMO• 1 • 0)		1 KPCP. 1.0)	1 LPCP. 1.0)					1. PCPI.1.1)			1. ALPHA.1.1)		1 ALPHA . 1 . 1)
KCPH CALL CALL CALL CALL	C COMPUTATION OF PCP	CALL ADOTR (P.CP	CALL FORMC(* CPCP PCP=RFAL(CPCP)	CALL SCALE (PCP.1.NBITSP.KPCP)		KUCTHEKPOP+KPOPO	FORMI (*	CPH.LT	FORMAT (LIN	CALL FORMAI(* ***********************************	(* * DIVIDE	FORMAT (* ********	FORMI (.	FORMI (CALL FORMAT(LINE,108) Go to 5000		CALL FORMI (*	C COMPUTATION OF ALPHA		PCP1=1PCP	=KO-LPCP	FORMR	CALL FORMICE LPCP # KD & LPCP	A=ROUNDR (RDR/IDOT.PCPI)		CALL SCALE(ALPMA.1.NBITSP.KAL)	CALL FORMR(" ALPHA SCALED
130. 132. 133.	136.	138	139.	141.	143.	144.	146.	147.	148.	149.	151.	152.	153.	154.	155.	157.	158.	160.	161	163.	164.	165.	167.	168.	169.	170.	172.

•		
i 	AP AND ACP	9
ا ر	DO 30 I*1.NPM1 ALPIWALPHA/IDOT	
30	AP(I)=CMPLX(ROUNDR(ALPI,REAL(P(I))),ROUNDR(ALPI,AIMAG(P(I)))) ACP(I)=CMPLX(ROUNDR(ALPI,REAL(CP(I))),ROUNDR(ALPI,AIMAG(CP(I)))) CALL FORMC(** AD	NDR (ALPI + AIMAG (P(I)))) OUNDR (ALPI + AIMAG (CP(I))
	1) LW H LAP 1) LW H LAP -AP H 1A1 + 1P + KM0	
! oo		
i U	CALL UPDATE(W.AP.W.NPM11.KW.KW0.LW.LAP.LW.LIM1.NBP.IGO)	IM1.NBP.160)
	KAINKA+KNO Triscification Goto Roco	
	TOTAL STATE OF THE	1 * * W * NP M 1 * 1)
	CALL SCALE(W.NPMIA.NBITSP.KW) CALL LIMIT(W.NPMIA.KW.KNO.LIMI.LIM2)	
	T 2 H 2 H 2 H 2 H 2 H 2 H 2 H 2 H 2 H 2	
	(* W SCALED	C. LAGN. 1.
	FORMI (* KEH	**************************************
	FORMIC* KM H KML + KMO	11.0)
	FORMI(" LW = LW + KW	11.0)
	FORMC (* ACP	: ACP . NPM1 . 1)
	LACP=LAL*LCF=KMU CALL FORMI(* LACP = LAL + LCP - KMO ***LAC	1.,LACP.1.0)
: 	UPOATE R	
ا ن		
	IADR=INV/ADR+0.5 RDR1=IRDR	
	LARI=KD=LRR	
	18081	1 - RDRT - 1 - 1 3
	FORMICE LARI = KD - LAR	* • LBB1 • 1 • 5
	UPDATE (R. ACP. R. NPMI 1. KR. KRO. LR. L.	P-LIMI - NBP - IGO
	KR+KR0	
	0.E0.0) GOTO 5000	
	CALL FORMC(* R 10.R.)	R. NDM

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1 . . L. RRO . 1 . 0 )
                                                                                                                                                                                                                                                                                                          1 . . KRRH . 1 . 0)
                                       . . R . NPM1 . 1 .
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11.LRRD.1.0)
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                                                 1 . . KRH . 1 . 0)
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                                                            1 . KR . 1 . 0)
                                                                     10.LR.1.0)
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                                                                                                                                                                                                                  KRR = KRRH - KRR0
LRR = 2*LR + KRR - KM
LRR0 = LRR - LRR0
                                                                                                                                                                                                                                                                              SYSTEM INTERRUPT
                                                                                                                                                                                                                                                                                                                                                                                  SYSTEM INTERRUPT
CALL SCALE(R.NPM12,NBITSP.KR)
CALL LIMIT(R.NPM12,KR.KR0,LIM1,LIM2)
                                                                                                                                                     CALL LIMIT (RDR. 1.KRR.KRRO. 0.KMO)
                                                                                                              CALL ADOTS (R.R.NPMI. CRDR, KM.0)
                                                           KR = KRH - KR0
LR = LR + KR
                                                                                                                                            CALL SCALE (RDR.1.NBITSP.KRR)
                                                                                                                                                                                                                                                                                                                                                     IF (LARD.LT.LART) 6010 4000
                                                                                                                                                                                                                                                F (KRRH.LT.KMO) GOTO 3000
                                       R SCALED
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                                                                                                                                                                 LRR=2+LR+KRR-KM
                                                                                   KARH=KRR+KRRO,
                                                                                                                                   RDR=REAL (CROR)
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260.	U	COMPUTE BETA	
261.	j		
262.	4000	Œ	
263.		_	•1)
264		SCALF (RETA.) . NATTSP. KBFT)	
265.		-	
266.		CALL FORMR(* BETA SCALED	•1)
267.		FURMI (* KBET	(0.
268.			10.
269.	i U		
270.	ပ	COMPUTE 8P	
271.	i U		
272.		DO 40 IEI.NPM]	
273.		BETAI=BETA/100T	,
274.	0	BP(I) = CMPLX(ROUNDR(BETAI.REAL(P(I))).ROUNDR(BETAI.AIMAG(P(I))))	I.AIMAG(P(I)))
275.		CALL FORMC(* BP :BP.NPM1.)	(40
276.		BET+LP+KBP+KM0	
277.		CALL FORMI(* LBP = LBET + LP - KMO 11, LBP, 1.0)	6
278.	i U		***************************************
279.	U	UPDATE P	
280.	i د		
281.		CALL UPDATE (R.BP.P.NPM1.1,KR.KRO.LR.LBP.LP.LIM1.NBP.1GO)	NBP • 160)
282.			
283.		10.EQ.0) GOTO 5000	
284.			•1)
285.		CALL SCALE(P.NPM12,NBITSP.KP)	
286.		CALL LIMIT (P.NPM12,KP.KPO.LIM1,LIM2)	
287.			
288.		0	
289.		CALL FORMC(* P SCALED	-11
290.		FORMI (* KPI	6
291.		FORMIC KP = KPH - KPO	•
292.		CALL FORMI(* LP = LP + KP 11.LP.1.0)	•
293.		FORMAT (LINE+)	
294.		IF (ITER.LT.ITERX) GOTO 1000	
295.		CALL FORMAT(" ************************************	
296.		FORMAT (* + SYSTEM I	
297.		FORMAT(* * NORMAL EXIT **	
298.		CALL FORMAT(* ***********************************	
299.	•	CALL FORMI (* ITERATION # 11,1TER.)	(0.
300	i ن		
301.	ပ	TERMINATION	

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(1.1MdN.W.)
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                                                            1. . NBW. 1.0)
                                         ..I.0.0)
                                                                                                                              CALL FORMC(* W (FLOATING-POINT)
CALL FORMAT(LINE.108)
RETURN
                                                                      CALL FORMI(* KPW = NBW = NBP
CALL FORMI(* LW = LW + KWF + KPW
CALL FORMC(* W (TO COMBINER)
FACTOREZ,0**(-LW-KS01)
DO 60 IS1.NPM1
X(1)=W(1)*FACTOR
                                        FORMI (* FINAL WEIGHT VECTOR
FORMAT (LINE, 108)
                            CALL SCATD(NPM1+2,KPW,W)
CALL FORMI(' FINAL WEIGH
       CALL FORMAT (PAGE-108)
LWELW+KWF+KPW
                                                              NO.
                                                            FORMI ( .
                                                              CALL
          5000
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SURDOUTINE ADOTB (A.A.A.A.B.KM.IC) SURDOUTINE ADOTB (A.A.A.A.B.KM.IC) SURDOUTINE ADOTB (A.A.A.A.B.KM.IC) SURDOUTINE ADOTB (A.A.A.A.B.KM.IC) SURDOUTINE AND B. TWO'S COMPLEMENT DOT-PRODUCT OF COMPLEX VECTORS A AND B. WITH CONJUGATE OPTION ON A INCLUDING MULTIPLIER TRUNCATION	PROGRAM : ADOTBIS ORIGINAL : SEPTEMBER 15. 1979 REVISION : MARCH 19. 1981 PREPARED BY : S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS DIV. TEMPE, ARIZONA 85282		OUTPUT : ADB - NOT PRODUCT OF SCALED A AND B	ENTRY POINTS : ADOTR PROGRAMS CALLED : SURROUTINE FUNCTION ENTRY	1	COMPLEX A.AI.8.ADB.ROUNDC DIMENSION A(1).B(1) ADB=0 IDOT=2**KM DO 10 I=1.N AI=A(1)/IDOT IF(IC.EQ.0) AI=CUNJG(AI) ADB=ADB.ROUNDC(AI.B(I)) RETURN END
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- N M + N O		10. 10. 22. 23.	25. 25.	20 20 20 20 20	30.	8 4 8 8 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9

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000	THIS FUNCTION WILL MULT THE RESULT TO THE	LTIP	THIS FUNCTION WILL MULTIPLY THE COMPLEX ARGUMENTS AND ROUND OFF THE RESULT TO THE NEAREST TWO'S COMPLEMENT INTEGER
0000	PROGRAM ORIGINAL REVISION		ROUNDCIS SEPTEMBER 15, 1979 MARCH 11, 1981
00000	PREPARED BY	•	DANIEL SYSTEMS DLA GOVER
0000	INPUT : Y		COMPLEX NUMBER TO RE MULTIPLIED BY Y
000	OUTPUT 1 ROUNDC	•	COMPLEX ROUNDED PRODUCT OF X AND Y
.	ENTRY POINTS	<u> </u>	ROUNDC
υυυι	PROGRAMS CALLED	••	SURROUTINE FUNCTION ENTRY
ں ر		H M M	M M M M M M M M M M M M M M M M M M M
,		i i i	
	DEATMAG(Y) ACEROUNDR(A.C) BDEROUNDR(B.D) BCEROUNDR(B.C) ANEROUNDR(B.C)		
	ROUNDC=CMPLX((AC-BD)+(BC+AD)) RETURN END	(8)	AD))

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2000 C	SECULTION WILLS	Ï	CACLACA ACCAMANA A MARKA
-	HE RESULT TO TH	Ψ	THE RESULT TO THE NEARESST TWO+S COMPLEMENT INTEGER
	PROGRAM	•• •	ROUNDRIS
	REVISION		SEPTEMBER 15- 1979 MARCH 11- 1981
	PREPARED BY	••	S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS DIV.
INPUT	× >-		REAL NUMBER TO MULTIPLY X
OUTPUT :	# ROUNDR	•	REAL ROUNDED PRODUCT OF X AND Y
ENTRY POINTS	OINTS	-	ROUNDR
PROGRAM	PROGRAMS CALLED	••	NONE
REAL X, Y,	ribererere Roundr	# # #	
IXY=XX	•		
IF (XY.LT.0 ROUNDREIXY	IF(XY.LT.O.) IXYEXY-1 ROUNDREIXY		
RETURN			

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		SURROUT	INE LIMIT	(XeNXeK	* X	SUBROUTINE LIMIT(X,NX,K,KO,LIMI,LIMZ)		SUBROUTINE LIMIT(X*NX*K*KO*LIMI*LIME)
• •		6 10 10 10 10 10 10 10	APPLIC	APPLICATION OF	I L	HARDWARE SCAL	SCALING LIMITS	
•	υU		PROGRAM	••	ر	s		
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•	υL		PREDAREN	٠ ۲	v	2	6 1. KERTESZ	25
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14. 15.	 	INPUT	 × 			NPUT VECTOR TO R	INPUT VECTOR TO BE LIMITED	
16.	ပ		×	•	z		ELEMENTS IN X	
17.	Ų.		X i	•	٠.	INPUT AND OU	OUTPUT BIT-SHIFT	
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33.					- (
24.	ا ب ب د	ENTRY POINTS	OINTS		}	LIMIT		
25. 26.	U U	PROGRAM	PROGRAMS CALLED	•	S	SURROUTINE	FUNCTION	ENTRY
27.	· U	,	 		٠			
28.	ပ				S	SCATO	• (SCATO
20.	טע				H H			
31.		1	ON X(1)					
32.		0 C						
34.		XIIIX +XO						
35.		IF (KH. G	LIM1)	GOTO 1000	0			
36.		KALIEN-KO	S I					
3	1000	IF (KH.LE.LIM2)	L1M2)	GOTO 2000	0			
39°		K=L1M2-K0 IC=KH-L1M2	KO Inc					
41.	2000	NS=IN-IO	á	CYCATOTANA	, ,	14.241		
44°		IF (NS.GE.0)	E.0) CALL		XX	NS+X)		

RETURN END

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PROGRAM : UPDATE:S ORIGINAL : AUGUST 15. 1979 REVISION : S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS TEMPE. ARIZONA 85282 INCORPORTING VECTOR INCREMENT VECTOR DIMENSIONALITY ISGN - UPDATING VECTOR INDICATOR I 1 X.Y CURRENT VECTOR VECTOR X I 1 X.Y KX - LOCAL SCALE OF VECTOR X LX - LOCAL SCALE OF VECTOR X LX - GLOBAL SCALE OF VECTOR X LX - GLOBAL SCALE OF VECTOR X LIMI - LOW RIT-SHIFT LIMIT LIMIT - LOW RIT-SHIFT LIMIT LIMIT - LOW RIT-SHIFT LIMIT LIMIT - LOW RIT-SHIFT LIMIT LIMIT - LOW RIT-SHIFT LIMIT LIMIT - LOW RIT-SHIFT LIMIT - LOW RIT-SHIFT LIMIT - LOW RIT-SHIFT LIMIT - LOW RIT-SHIFT LOW					THIT JUNEAU	2
PREPARED BY: S. M. DANIEL & I. KERTESZ RADAR SYSTEMS ANALYSIS GROUP MOTOROLA GOVERNMENT ELECTRONICS TEMPE. ARIZONA 85282 INPUT: X CURRENT VECTOR VALUE NX CURRENT VECTOR NALUE NX LOCATION SOURTENENT I X ** CURRENT VECTOR NALUE NX LOCATION SOURTENENT I X ** CURRENT VECTOR VALUE NX LOCATION SOURCEMENT I X ** LOCATION SCALE OF VECTOR X LX KX LOCAL SCALE OF VECTOR X LX LX LX LX LX LX LOCAL SCALE OF VECTOR X LX LX LX LX LX LX LX LOCAL SCALE OF VECTOR X LX LX LX LX LX LX GLOBAL SCALE OF VECTOR X LIMI LIMI LIMI LIMI LIMI LIMI LIMI LIM		PROGRAM	•	UPDATEIS		
PREPARED BY : 5. M. DARADAR SYMOTOROLA TEMPE. AT TEMPE. AT TEMPE. AT TEMPE. AT TEMPE. AT TEMPE. AT TEMPE. AT TEMPE. AT TEMPE. AT UPDATING I X TEMPE. AT TEMP		ORIGINAL REVISION	₩ ₩	AUGUST 15.		
INPUT: X CURRENT VECTOR VALUE NX VECTOR DIMENSIONALITY ISGN ADDITION/SUBTRACTION INDICATOR I X+Y LOCAL SCALE OF VECTOR X LX LX LX LX LX LX CLOBAL SCALE OF VECTOR X LX GLOBAL SCALE OF VECTOR X LX CTOCOR SCALOR TO TO TO TO TO TO T		PREPARED		S. M. DANIE RADAR SYSTE MOTOROLA GO	L & I. KE	
V VECTOR DIMENSIONALITY ISGN - UPDATING VECTOR INCREMENT ISSN - 1 X X Y LOCAL SCALE OF VECTOR X LX LOCAL SCALE OF VECTOR X LX LOCAL SCALE OF VECTOR X LX LOCAL SCALE OF VECTOR X LY GLOBAL SCALE OF VECTOR X LIMI - 10W RIT-SHIFT LIMIT LIMI - 10W RIT-SHIFT LIMIT LX GLOBAL SCALE OF VECTOR X INTRINSIC SCALE OF VECTOR X INTRINSIC	INPUT	**************************************	•	ZINE TARRES	UNA 85282	
NX ISGN - VECTOR DIMENSIONALITY ISGN - ADDITION/SUBTRACTION INDI 1		>	•	UPDATING VE	TOR VALUE	
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LX GLOBAL SCALE OF VECTOR X GLOBAL SCALE OF VECTOR X LIM1 LIM2 GLOBAL SCALE OF VECTOR Y LIM1 LIM2 LIM3 HIGH BIT-SHIFT LIMIT LX GLOBAL SCALE OF VECTOR Z GLOBAL SCALE OF VEC		×	•	LOCAL SCALE	VECTOR	
CUTPUT: LY GLOBAL SCALE OF VECTORY LIM1 LOW RIT-SHIFT LIMIT LIM2 LOW RIT-SHIFT LIMIT LIM2 LOW RIT-SHIFT LIMIT LIM2 LOW RIT-SHIFT LIMIT LIM2 LOW RIT-SHIFT LIMIT LIMIT LOW RIT-SHIFT LIMIT LOW RIT-SHIFT LIMIT LOW RIT-SHIFT LIMIT GLOBAL SCALE OF VECTOR Z GLOBAL SCALE OF VEC		0 ;	•	INTRINSIC S		
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OUTPUT : Z UPDATED VECTOR LZ GLOBAL SCALE OF VECTOR LZ GLOBAL SCALE OF VECTOR 1 1 NORMAL OPERATION 1 1 NORMAL OPERATION 0 1 DYNAMIC RANGE INTER ENTRY POINTS 1 UPDATE PROGRAMS CALLED 1 SUBROUTINE FUNCTION FORMAT SCATO		LIM	• •	GLUBAL SCALE	OF VECTOR	>
OUTPUT: Z LZ GLOBAL SCALE OF VECTOR Z IGO RETURNED GO/NO-GO CONDIT 1 1 NORMAL OPERATION 0 1 DYNAMIC RANGE INTER ENTRY POINTS 1 UPDATE PROGRAMS CALLED 1 SUBROUTINE FUNCTION FORMAT SCATO		LIMZ	•	HIGH BIT-SH	FT LIMIT	
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ENTRY POINTS & UPDATE PROGRAMS CALLED & SUBROUTINE FUNCTION FORMAT SCATA				1 : NORMA	L OPERATION	
SCATO	:	INTS		•		
	PROGRAMS	CALLED	•	SUBROUTINE	FUNCTION	ENTRY
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                                                                                                                            IF(LYX.LT.LIMIA.OM.LYX.GT.LIMZA) GOTO 3000
IF(LYX.LT.0.OR.LYX.GT.LIMZA) GOTO 1000
                                                                                                                                                                             IF (LYX.LT.LIMIA.OR.LYX.GE.0) GOTO 2000
                                                                                                                                                                                                                                                                                     (F(NS.LT.0) CALL SCATD(NXZ.NS.Y)
                                                                                                                                                                                                                                                        CALL SCATD(NX2.NS.X)
                                                                                                                                                                                                                                                                  (F (NS.GE.0) CALL SCATU(NX2,NS.X)
                                                                                                                                                                                                                                                                                                                            KX = KXH - KX0
OMPLEX X(1)+Y(1)+Z(1)
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                                                                                                                    LXX
                                                                   LIMZA=LIM2-LIM1
                                                         LIMIA=LIMI-KXH
                                                                                      FORMI (.
                                                                                                                   CALL FORMI(*
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                                                                                                         CALL FORMIC
                                                                                                                                                                                                                                                         IF (NS.LT.0)
                                                                                                                                                                                                KXHHKXH+LYX
                                               XXH=KX+KX0
                                                                                                                                                                                                          KX#XXI-KXC
                                                                                                                                                                 60TO 2000
                                                                                                                                                         -Y=LY-LYX
                                                                                                                                                                                                                   XXTXXTXX
                   -YX=LY-LX
                                                                                                                                                                                                                                     NX2=NX+2
                                                                                                                                                                                        IX=-LYX
                                                                                                                                                Y=LYX
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          60=1
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1 . PCAN : 1 . 5) 1 . SC . NS . 1) · · I · 0 · 0) SC(IS)=SC(IS)+S1(IS,IP)+W(IP)
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IF(LW.LI.0) CALL SCATU(NS2,-LW.SC)
IO 20 IS=1.NS
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SC(IS)=SC(IS)+NS
PC=PC+CABS(SO(IS))+NS
PCAN=100.
IF(PC.NE.0) PCAN=10+ALOG10(PO/PC)
CALL FORMAT(PAGE.100) CALL FORMIT COMBINED PORT SIGNAL CALL FORMAT (LINE, 108)
CALL FORMCT SC CALL FORMC(* SC CALL FORMAT(LINE.108) CALL FORMAT(LINE.108) CALL FORMAT(LINE.108) RETURN 20 **44 55** 48. 69. 50. 50. 50. 56. 59. 59.

binary module has been created by compilation. A general form of a Job Control Lancing (JCL) program for doing this is shown in Table 4-4.

Table 4-4. JCL Program, JCL:B

1 - 1.000 !JOB 1269,DANIEL(8512),7,8LDG90
2 - 2.000 !LIMIT (TIME,1),(UO,10),(CO,16),(ACCOUNT)
3 - 3.000 !SET M:SI/NAME:SIINISAVE
4 - 4.000 !SET M:BO/NAME:BIOUT:SAVE
5 - 5.000 !FORTRAN LS.NS.BC.SI.BO

Note that any source file, FILE:S, may be converted to its binary version, FILE:B, by the name-substitution batch command:

!BATCH JCL:B 'NAME' = FILE

4.1.5 Executable Load Module

The next step toward program execution is the creation of an executable load module. This involves the linking of all binary modules which together contain all the subroutines and functions referenced in the complete program suggested by the tree diagram of Figure 4-1. For the present case, this can be accomplished through the execution of a JCL program such as JCLBCRM:BL, as shown in Table 4-5. It can be seen there that all the binary

Table 4-5, JCL Program, JCLBCRM:BL

1	_	1.000	IJOB :	1269 DANIEL (8512)	7,8LDG90
2	•	2.000	ILIMI'	T (TIME+1)+(U0+2)	(CO+16) + (ACCOUNT)
_	-	3.000	1	JCLBCRM:BL	
4	-	4.000	IPCL		
5			Ċ	BCRMMAIN:B	OVER BCRMIB
6		6.000	_	BCRMSETIB	
7	-	7.000	-	RWIB	
8	_		č	FORMAT : B	
9	-	7 1 1 1	č	BCRMEXEC : B	
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ii	_	11.000	•	SCATD:B	
12	_	12.000		CBEML : B	
		_	-	_	
13		13.000	_	SCALEIB	
14	-	14.000	C	BIGSGN:B	
15	•	15.000	С	BCREMLIB	
16	-	16.000	С	ADOTB:B	
17	-	17.000	C	ROUNDC : B	
18	-	18.000	č	ROUNDR	r R
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21	-	21.000	C	CSEML # B	
22	•	22.000	ILYNX	BCRM:B	OVER BCRMIL

modules of BCRM are in the process of concatenation into one composite binary module, BCRM:B. After the computer system supplies all the system references, the linking takes place, and the resulting module is place into a file called BCRM:L. This file is the executable load module of program BCRM.

The load module can be executed with a "RUN" command. An example of this is the JCL program, JCL:X in Table 4-7. It assigns an input file (suffix:D), and an output file (suffix:O) to the executable load module (suffix:L) for the duration of the job. When JCL:X is batched, "BCRM" is substituted for "NAME". Thus BCRM:L will read input data from BCRM:D, and write output data into BCRM:O.

The load module BCRM:L may now be executed via a JCL program, JCL:X, given in Table 4-6.

Table 4-6. JCL Program, JCL:X

- 1 1.000 IJOB 1269.DANIEL(8512).7.BLDG90
- 2 . 2.000 |LIMIT (TIME+1)+(UO+50)+(CO+24)+(ACCOUNT)
- 3 3.000 ISET F:105/NAMEID
- 4 4.000 ISET F:108/NAME:0
- 5 5.000 !RUN (LMN.NAME:L)

4.1.6 Output Data File - BCRM:0

The output data file, BCRM:0, produced by the BCR emulation program is listed under Table 4-7 that follows. It consists of two major parts. The first part is a reprint of the input data file, BCRM:D. This is a desirable convenience to the user and, of course, helps to completely identify the particular case executed.

The second part of BCRM:0 is the actual emulation results obtained from the execution of BCRM:L. It gives a listing of all sampled port signals and quantities C and \underline{b} according to available print options. Then, starting with a number of operational specifications including C and \underline{b} data, an exhaustive numerical description of the adaptive fixed-point arithmetic of the BCR process follows.

Included, as shown is the initialization part consisting of loading initial values for \underline{w} , \underline{r} and \underline{p} into the Vector Storage RAM, setting a global scale reference for \underline{r} and \underline{p} and computing $||\underline{r}||^2$ with its global scale. Following subsequently, is the complete arithmetic activity of the iterative portions of the BCR process. The left-hand-side of the output is reserved for variable names and pertinent local and global scale equations. The right-hand-side includes the corresponding computed values as would be produced by a 16-bit BCR processor implementation.

Table 4-7. Output File of the BCR Emulation Program
Benchtest Example (See Figure 2-2, PM 8512-04)

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2		31.0	2.0	12.0	36.0	-30.0	-1.0	12.0	-17.0
n n n		31.0	2.0	12.0	36.0	-30.0	-1.0	12.0	-17.0
R SCALED	•	3968.0	256.0	1536.0	4608.0	-3840.0	-128.0	1536.0	-2176.0
KR = KRH - KRO LR = LR + KR CROR ROR KRR + KRR - KRR LRR = Z-LR + KRR - KM LRRD = LRR - LRRO		8 934.0 29888.0 5	•						

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(FLOATING-POINT)

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4.2 BCR Processor Performance

The BCRM program described above is useful in evaluating the adaptive nulling performance of a practical BCR processor implementation employing 16-bit adaptive fixed-point arithmetic. As already mentioned, Table 4-7 includes the detailed arithmetic activity of the BCR processor for the case of the benchtest example. The BCR processor performance for this case and two other examples is compared to that of the 32-bit floating-point simulation performed via BCRS in Project Memorandum 8512-04.

4.2.1 Benchtest Example

The BCR processor performance for the benchtest example is summarized in Table 4-8 where it is contrasted to the actual simulation results reported

Table 4.8. BCR Processor Performance
Benchtest Example (See Figure 2-2, PM 8512-04)

ITERATION	EM	ULATION		SIMULATION	
TIERATION	<u>r</u> ²	$\ \underline{\mathbf{r}}\ ^2/\ \underline{\mathbf{b}}\ ^2$	(Ф)	$\ \underline{\mathbf{r}}\ ^2/\ \underline{\mathbf{b}}\ ^2$	(qp)
0	17,888 x 2 ¹⁷	0.00		0.00	
1	26,602 x 2 ¹¹	-16.34		-16.34	
2	29,888 x 2 ⁻⁷	-70.01		-69.65	
P _C (<u>w</u>)/P	(dB)	-25.03		-25.24	

in Project Memorandum 8512-04. To be noted under the emulation results is a column containing the actual 16-bit fixed-point values of $\|\mathbf{r}\|^2$ at initialization and the two iterations that follow. These values may be read directly from Table 4-7. Since the initial weight-vector estimate, \mathbf{w}^0 , is taken to be $\mathbf{0}$, $\|\mathbf{b}\|^2$, is identical to the initial value of $\|\mathbf{r}\|^2$, 17,888 x 2¹⁷. This fact was used to construct the second column showing the relative gradient metric $\|\mathbf{r}\|^2/\|\mathbf{b}\|^2$. When contrasted with the available simulation results, the agreement is impressive. What is more important is the actual combined power level achieved by the processor. Compared to that of a 32-bit floating-point simulation, it is degraded only by 0.21 dB. This relatively small adaptive nulling degradation was, in part, due to the adaptive fixed-point arithmetic employed by the BCR processor. Of course, part of the degradation is due to the reduced numerical resolution in the sampled signals.

It should be noted in Table 4-7 that the BCR processor terminated processing during the second iteration. In fact, a build-in system interrupt associated with the gradient convergence condition, $\|\underline{r}\|^2/\|\underline{b}\|^2 < 2^{-15}$, came into effect. Since $\underline{w}^0 = 0$, this meant that, at the second iteration, the global bit-shift, LRR, of $\|\underline{r}^0\|$ exceeded that of the initial global bit-shift, LRRO, of $\|\underline{r}^0\|$ or $\|\underline{b}\|^2$ by more than 15. In fact, LRR-LRRO took a value of 24.

Of interest here is the floating-point equivalent of the 12-bit version of the processor-estimated weight-vector and its comparison to the weight-vector estimated via floating-point estimation. This comparison is given in Table 4-9.

Table 4-9. Comparison of Simulation/Emulation Weight Vector Estimates
Benchtest Example (See Figure 2-2, PM 8512-04)

WEIGHT- VECTOR COMPONENTS	<u>w</u> ^S	<u>w</u> e	$\Delta \underline{w} = \underline{w}^{S} - \underline{w}^{e}$
1 2 3 4	-0.37375 - j0.28405 -0.28686 + j0.37356 -0.37553 + j0.28835 0.28409 + j0.37616	-0.38623 - j0.29292 -0.29565 + j0.38745 -0.38671 + j0.29810 0.29345 + j0.38842	0.01248 + j0.00867 0.00879 - j0.01389 0.01118 - j0.00975 -0.00936 - j0.01226
<u>₩</u> :	Weight Vector Estimat Weight Vector Estimat	e Via Simulation e Via Emulation (12-bi	t Equivalent)

At first glance, it is surprising to notice the rather large deviation between the components of the two weight-vector estimates. However, even with the nearly 3% magnitude deviation, the adaptive performance of the BCR processor has not suffered. A probable reason why such a deviation would not give rise to a commensurate degradation in performance is that the covariance C is not full-rank. As such, a weight-vector deviation from ws would not necessarily imply poor nulling.

4.2.2 Blinking Source Example

The next example chosen for emulation was the blinking source example discussed in Project Memorandum 8512-04. Its scenario and system description is given there in Figure 3-1. Its simulated BCR convergence characteristics may be found in Figure 3-1 of the same memorandum.

Figure 4-1 contrasts the emulated BCR convergence characteristics with those predicted via simulation. To be noted, immediately, is the degraded behavior of the relative gradient metric, $\|\mathbf{r}\|^2/\|\mathbf{b}\|^2$ in the case of the emulation. However, with a gradient convergence threshold of $\|\mathbf{r}\|^2/\|\mathbf{b}\|^2 < 2^{-15}$, the BCR processor will terminate processing at the second iteration. At that point the relative combined power level of -25.2 dB almost matches the corresponding simulation value. Motivated by this fact, the BCR

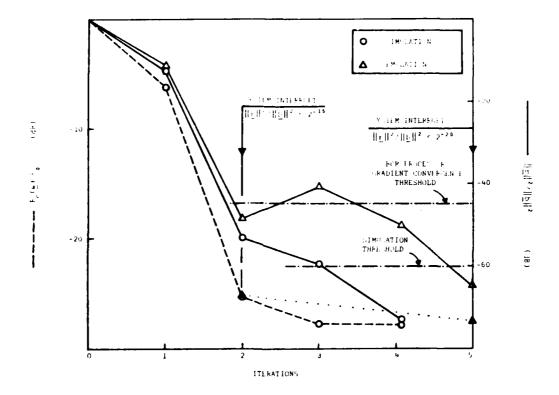


Figure 4-1. Simulation/Emulation Comparison BCR convergence Characteristics Blinking Source Lxample (See Figure 3-1, PM 8512-04)

processor threshold was lowered to the simulation threshold of -60 dB. As shown, the BCR processor cross it in the 5th iteration, one more iteration than indicated in the simulation case. The combined power level achieved by the BCR processor in the 5th iteration is -27.50 dB compared to -27.79 dB in the 4th iteration of the simulation.

The present example serves to illustrate the behavior of BCR convergence with reduced numerical accuracy. The nontonic behavior of the gradient metric with the 34-bit floating-point arithmetic is not maintained with the 16-bit adaptive fixed-point BCR processor implementation. This is due to two fundamental reasons. First, in the emulation, the word lengths

in the main and auxiliary signal samples are 10 and 8 respectively, certainly less accurate than the floating-point versions with five significant digits used in simulation. Second, the CG-based weight-estimation process would certainly give rise to a larger roundoff error with 16-bit arithmetic than with 32-bit floating point. Of course, a better comparison between emulation and simulation would be possible if the first of these possible causes of inaccuracy were to be eliminated. That is, if the simulation were to take the 16-bit C and b quantities and exercise the CG process with a 32-bit floating-point arithmetic, the only discrepancy in convergence characteristics of the BCR emulation would be truly confined to the CG-stage.

A final comment is in order with respect to this example. Based on the results, it is clear that the gradient convergence criterion, $\|\underline{r}\|^2/\|\underline{b}\|^2 < 2^{-20}$ was used. If the latter stopping condition were used, along with a maximum iteration count of 5, the indicated nulling level would be achieved. If only 4 iterations were allowed, the number of adaptive weight-vector components, then the nulling level would be somewhere between -25.21, at the second iteration, and -27.40 in the 5th. It would appear then that the stopping criterion for the BCR processor must be dictated first by the maximum number of iterations and then by the gradient convergence threshold.

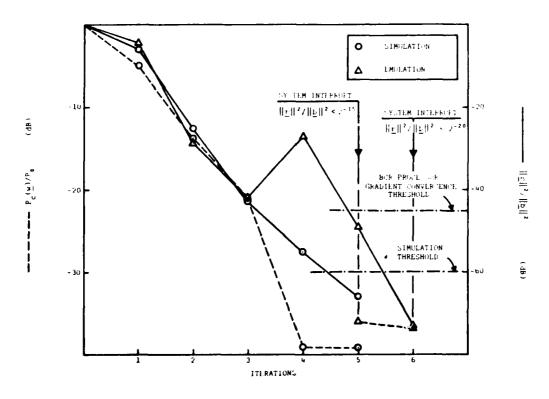


Figure 4-2. Simulation/Lmulation Performance Companison BCK Convergence Characteristics Wideband Source Example (See Figure 3-10), FM 8512-04)

4.2.3 Wideband Example

The next example considered was the wideband source example whose scenario and system description may be found in Figure 3-10 of PM 8512-04. The BCR processor convergence characteristics for this example are contrasted to the simulation results in Figure 4-2.

As for the previous, Figure 4-2 includes the complete relative gradient profile for the six iterations needed to cross the lowest threshold of -60 dB, where $\|\underline{r}\|^2/\|\underline{b}\|^2 < 2^{-20}$. The combined power nulling level achieved is -36.67 dB, a degradation of less than 3.00 dB with respect to the simulation performance after five iterations.

Using the higher threshold, the BCR processor converged in five iterations. The achieved nulling level was about 3.50 dB worse than the simulation level. Significantly, the BCR processor nulling improved only by 0.5 dB between the fifth and sixth iterations.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The implementation of a BCR adaptive processor has been presented in considerable detail and its performance has been evaluated. More specifically, a 4-port BCR adaptive processor block diagram has been described qualitatively and quantitatively. An exact representation of its 16-bit adaptive fixed-point arithmetic was incorporated into a computer emulation program in order to evaluate the numerical effectiveness of the mechanization. Three examples have been included to demonstrate the floating-point simulation. In each case, the BCR processor provided excellent numerical accuracy and, more importantly, achieved a nulling performance that compared well with that predicted via simulation.

Although a 4-port BCR processor was described, the reader can easily extend the design to a higher-dimensionality system. From the practical point of view, however, it may be undesirable to extend this design byond a certain dimensionality. For example, bus-widths that may be required will quickly become unwieldy. Optical fiber bussing may be incorporated to multiplex the parallel vector signals one component at a time, thus alleviating this problem.

A more desirable alternate design approach would be a serialized implementation which would be suitable for any desired dimensionality, within some practical limits. Accordingly, the CPU could be replaced with a single complex multiplier/accumulator design and all busses will be limited to a single complex word-width. This approach will allow flexibility of design and also take advantage of the emerging VHSIC technology.

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